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Planning Methodologies for Analysis of Land Use/Water Quality Relationships Case Study Application

Betz Environmental Engineers, Inc, Plymouth Meeting, Pa

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PLANNING METHODOLOGIES FOR ANALYSIS OF LAND USE/WATER QUALITY RELATIONSHIPS: CASE STUDY APPLICATION

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(215) 825-3800

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The objective of this report is to present a detailed methodology and a case study analysis of how runoff from urban and urbanizing areas affect water quality. The study outlines existing and projected land uses in the relatively small Wissahickon Basin (Pennsylvania) and its related water quality problems. The methodology employs a simple mass balance determination of sediment and absorbed materials based on a modified universal soil loss calculation. It is adopted to field study data and other local conditions, such as climate, slope; and patterns of residential and commercial development.

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Walter

FROM: Walter Groszyk, Deputy Director
Water Planning Division (WH-554)

TO: Regional Water Division Directors
208 Coordinators

Information Memorandum: INFO-78-5

This report by Betz Environmental Engineers presents an application of a planning methodology for the analysis of land use-water quality relationships. It is a follow-up to a previous Betz study entitled "Planning Methodology for Analysis of Land/Use Water Quality Relationships," Water Planning Division, EPA, 1976. The emphasis of this report is on urban and urbanizing areas, and in particular, the study emphasizes possible effects from new development. In order of presentation the report outlines some pertinent land use and receiving water quality relationships, highlights typical problems, and provides a detailed description of the methodology.

The methodology is applied to the Wissahickon watershed, a "typical" urban watershed. Technically the report attempts to estimate pollutant runoff by land use, allows calibration to reflect local conditions, and determines those BMP's which should be most effective in reducing runoff.

This methodology should require less hydrologic and storm data than dynamic storm modeling. It uses a simple mass balance calculation based upon the universal soil loss equation. This equation has been found to have broad applicability but its usefulness for predicting erosion-related components such as toxic transport is under intensive review. The methodology does provide a practical way of estimating sediment loading and does relate field survey observations to the mathematical model. It does not provide adjustments for hydrologic modifications, or directly assess water quality impacts. If used for priority ranking of major sediment contributors the method should be useful for comparing relative differences between BMPs. It does not provide accurate predictions for soluble constituents or work well for slow snow-melt or slow rainfall-events.

A structure like Betz's is needed to begin sorting out NPS problems. Other methods are of course available such as found in the "Areawide Assessment Procedures Manual, EPA, 1976" which does offers a much broader discussion on NPS problem assessment. At this time, however, the state-of-the-art of NPS modeling does not offer any one best method that can closely predict absolute differences between control strategies. Long term data should, ideally, be available for a wide range of actual runoff events. This is seldom the case. Methods like these that permit an orderly process of estimating the effects of runoff are a practical necessity.

Please disseminate this handbook to only those agencies who you believe can make wise use of it. Extra copies may be requested from the Water Planning Division Library (WH-554), Washington, D. C., 20460 (FTS 755-6993) or through Bill Cogger (FTS 426-2522) of this office.

Attachment

PLANNING METHODOLOGIES FOR ANALYSIS OF LAND USE/WATER QUALITY RELATIONSHIPS: CASE STUDY APPLICATION

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PROJECT OFFICERS: WILLIAM J. COGGER
WILLIAM C. LIENESCH

By

BETZ ENVIRONMENTAL ENGINEERS, INC.
PLYMOUTH MEETING, PENNSYLVANIA

PROJECT DIRECTOR: WILLIAM K. DAVIS
PROJECT MANAGER: FRANK X. BROWNE

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I

INTRODUCTION

The purpose of this report is to present a simplified planning methodology for 208 water quality management agencies. Existing methodologies were adapted in the development of the present methodology. The application of the methodology will allow 208 agencies to:

- Estimate general values of pollutant runoff coefficients by land use and type of land
- Determine how to calibrate values of pollutant runoff coefficients to reflect local conditions, including climate, soil, slope, nature of water bodies, and ground cover where such conditions affect water quality
- Determine those land use and land management controls which are most effective in reducing pollutant generation and discharge in the specific 208 area

The emphasis of this report is on urban and urbanizing areas with stress on single family residential, multi-family, residential, and commercial land uses. In particular, the study emphasizes residuals discharged from new development.

Section II outlines some pertinent land use and receiving water quality relationships and typical problems. Section III provides a detailed description of the methodology developed to analyze these relationships. The methodology is applied in Section IV to a case study for a typical urbanizing watershed. Finally, Section V presents an evaluation of the methodology, a summary of typical problems encountered in applying the methodology, and recommendations for application.

A glossary of terms is provided for commonly used jargon of water quality planners, and for the shorthand abbreviations of the simple formulas. Supportive data and actual calculations are assembled in a detached summary. These data can be provided by contacting the EPA Water Planning Division (WH-554) library in Washington, DC, 20460.

These sections are followed by a glossary of terms used throughout the report and appendices which include supporting data and analysis and sample calculations.

II

LAND USE/WATER QUALITY ANALYSIS

A. EXISTING METHODOLOGIES

There are numerous evolving methodologies to use to evaluate nonpoint pollution and formulate best management practices for inclusion in water quality management plans. These methodologies can be grouped into four major categories: (1) stormwater modeling, (2) environmental synthesis, (3) statistical relationships, and (4) others. A brief description of each methodology, including a summary of salient characteristics and advantages and disadvantages, follows.*

1. Stormwater Modeling

There are essentially two types of stormwater modeling: (1) Stormwater Management Model (SWMM) developed under the auspices of EPA; and (2) the Storage-Treatment-Overflow-Runoff Model (STORM), developed by Water Resources Engineers and later expanded by the U.S. Army Corps of Engineers. Both are dynamic models which include the hydraulics of stormwater. SWMM includes the response of receiving water quality as well as the hydraulics and transport of pollutant loads. Both would encompass pollutant yields of dissolved material, suspended material and settleable material, and both use the universal soil loss equation to simulate pollutant scour and erosion from pervious land cover.

These models present an adequate approach towards solving water quality management problems. The dynamic nature of the models allows simulation of storm response, thus providing criteria for exploring hydraulics, and structural and non-structural best management practices alternatives. SWMM has the added advantage of determining recipient water quality. Both models have a disadvantage: large amounts of data are required and the simulation of hydraulics is complex. Simplifications and aggregation to compensate for lack of detailed data may result in erroneous results that are no better or possibly worse than simpler approaches. Applying this methodology is costly and out of reach of many 208 agencies.

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* More detailed descriptions of these methodologies can be found in references 13, 14, 16, 19, 23, 26 and 37 of the bibliography.

2. Environmental Synthesis

The common characteristic of this group of methodologies is that they attempt to synthesize multiple environmental objectives to develop an overall land use and public facility plan. Large regions are subdivided into homogenous units based on biologic capability, suitability and feasibility. The methodology uses overlays of each of these criterion to highlight problem areas or inconsistencies in capabilities and objectives.

The methodology is usually less costly than others in its application but is wanting in answers normally required by planners who are developing water quality management alternatives. The resulting outputs are usually insufficient to quantitatively assess the magnitude of nonpoint loads and the degree of abatement required to meet water quality goals.

3. Statistical Relationships

The objective of this methodology is to develop statistically sound relationships between land use and pollutant loads and between pollutant loads and the quality of receiving waters and hydrologic variables. It attempts to identify land uses responsible for various pollutants, thus providing a criteria for quantitative assessment of pollutant loads and their subsequent control.

This approach is economical and should be sound, but there is no assurance of success because apparently valid statistical relationships may not stand up to empirical evidence or data with a low statistical correlation may have a practical connection. Pollutants eminate from a variety of land-soil uses, thus statistically sound criteria may require a large sample size or highly sophisticated statistics. This may pose a problem in expense and outstrip practical comparisons and inferential testing of statistical conclusions. Statistical sorting and consolidation may however be the only way of dealing with these complex conditions. Another problem with statistical analysis is that pollutant loads from similar land uses vary, depending on slopes, soils and proximity to stream. Also, the complexities of the hydraulics of one storm compared to other storms of different intensity or duration presents obstacles in statistically correlating data. The statistical analysis can take apparent wide variability into account, but practically it is limited in its applicability to reasonably similar sets of land use conditions (land uses with common slopes, soils, stream proximity, etc.).

B. PROBLEMS OF NONPOINT SOURCE LOAD ASSESSMENT

Determining nonpoint pollution problem areas and wasteload allocations for a 208 area is a complex task. Rarely is the existing data base adequate to permit a thorough analysis. The manpower and time required to augment and provide a complete data base are usually beyond the budget of the 208 planning agency. The agency is usually forced to compromise; exchanging comprehensive analyses for a limited effort. The following factors are worthy of consideration when addressing this problem.

1. The presence of nonpoint source loads in streams is caused by runoff from storms. Samples of receiving stream water should be taken during and immediately following a storm at strategic locations in the stream where the presence of nonpoint loads is suspected. The sampling should be thorough enough to allow for the construction of hydrographs and pollutographs of each pollutant considered and to relate them to total storm rainfall. Extrapolation of periodic samples (grab samples) of water quality data to storm loads should be avoided if possible. The Wissahickon Watershed Case Study presented in Section IV indicated that better than 95% of the total annual sediment load occurred within one or two days following significant storms. In some streams, 95 percent of the load occurred during less than 6 percent of the total days in the year. The practice of periodic random sampling increases the chances that significant storm loadings would be missed; and results extrapolated from this sampling could be misleading.

2. Nonpoint pollution runoff from various land uses depends not only on the land use and severity of the accumulated load on the land but on a complex relationship of other factors such as slopes, soils, drainage density and degrees of natural and man-made controls. Actual runoff loads from typical land uses and terrain within the 208 study area should be measured in streams during and following storms, to verify desk top projections. If this is beyond the scope of the study, runoff measurements from similar areas may be used, but care should be taken that such factors as land use, terrain, soils and climate are similar. Unverified runoff projections should be used very carefully for planning purposes or sparingly if qualitative data, for example, Fish census or on site examination, suggests these projections are in error.

3. Visual observations of land use and stream conditions before and after storms are extremely helpful in locating and verifying nonpoint problems and sources. However, these observations yield only qualitative analysis

of problem areas and need some fixed framework (model or mass balance) before the observations can be effectively utilized for wasteload allocations.

C. OVERVIEW OF METHODOLOGY

The goals of this study can be summarized in the following scenario:

> Imagine a small to medium sized metropolitan area in which substantial land development and suburban growth is expected to take place in the future. Water quality is known to be affected by point sources; but the relative importance of nonpoint sources is uncertain. The 208 funds available for NPS/IPS (nonpoint source/intermittent point source) analysis will probably not permit calibration and operation of non-steady-state receiving water models for all streams affected by urbanization, or permit a broadly-based program of storm water modeling. Our task is to tell them how they might proceed in assessing NPS/IPS problems, setting priorities, evaluating control measures, and developing a cost-effective control plan which is coordinated with other planning activities in the area.

Pursuant to these goals, various techniques and methodologies were examined. The methodology developed is a mixture of what was deemed the best qualities of the methodologies previously presented and one which would recognize and circumvent the highlighted problem areas. Emphasis was placed on using techniques requiring talents and capabilities normally found in 208 agencies. Complex hydrologic modeling algorithms were avoided.

The methodology provides a relatively simplified approach for the analysis of land use/water quality relationships. The primary components of the methodology include field investigations, stormwater runoff monitoring, application of a simplified form of the universal soil loss equation to calculate nonpoint loads, mass balance analysis using pollutant generation and in-stream water quality analysis, and ranking of best management practices.

This mass balance model provides the framework to identify land uses, terrain and soil conditions, and controls. The use of a model makes it possible to modify loading factors based on visual observations. The total mass balance model is calibrated to conform to the observed stream loads. The model provides a simple base for exploring promising land management alternatives and nonpoint wasteload allocations and their impact on receiving water quality. The model does not provide a framework for exploring alternative hydrologic routings or alternatives other than a gross analysis of their total impact to receiving waters.

The details of the methodology are presented in Section III, including all applicable criteria. The methodology was applied to a typical case study "The Wissahickon Watershed." Details of the case study application are presented in Section IV. An evaluation of the methodology is presented in Chapter V.

III

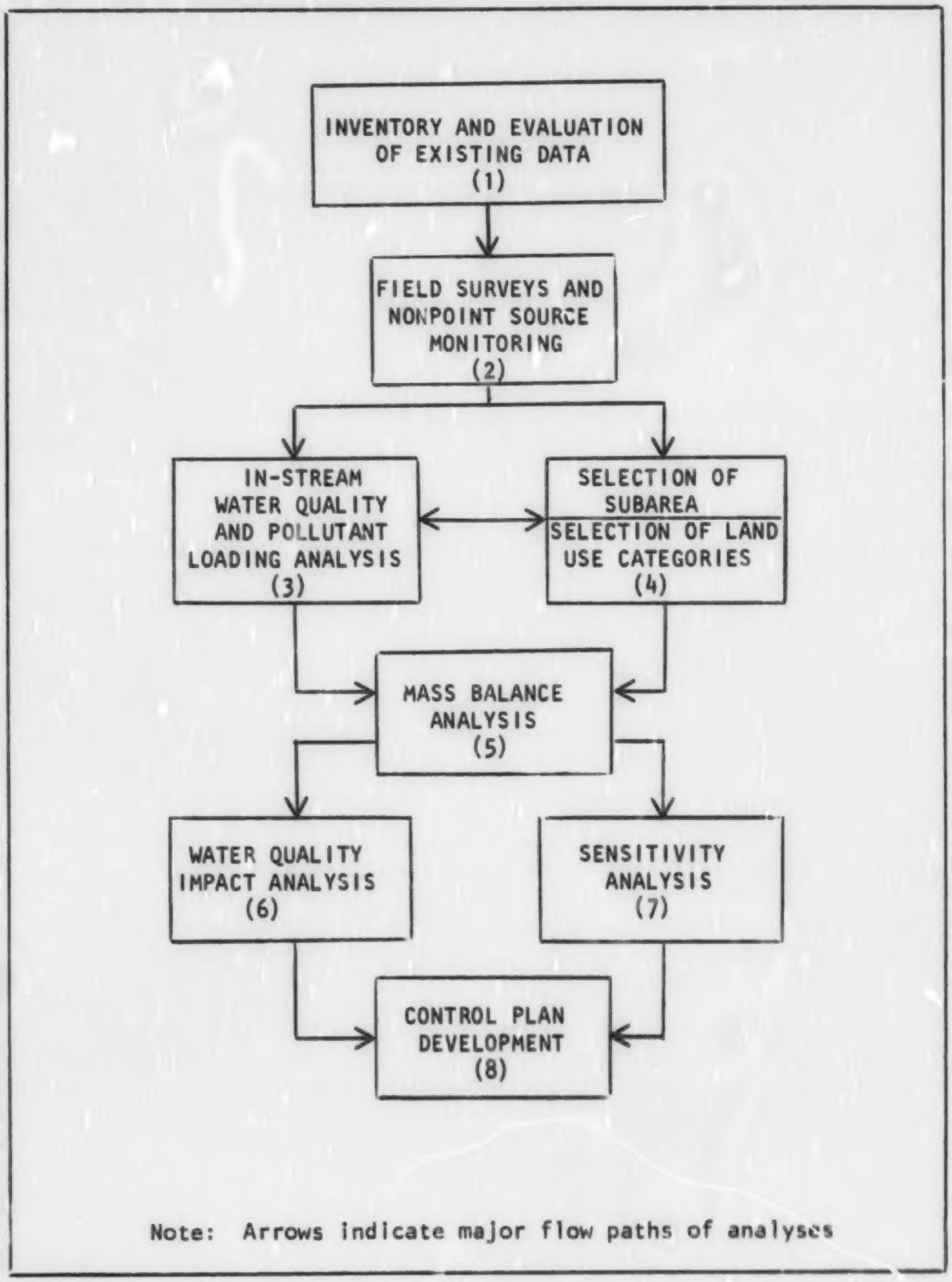
ANALYTICAL METHODOLOGY

A. INTRODUCTION

The methodology presented in this section provides a simplified approach for the analysis of land use/water quality relationships. The primary components of the methodology include field investigations, stormwater runoff monitoring, application of a modified universal soil loss equation to calculate nonpoint source loads, mass balance analysis using pollutant generation and in-stream water quality data, and control plan development. A schematic representation of the methodology is presented in Figure 1. The total methodology consists of the following components:

1. Inventory and Evaluation of Existing Data
2. Field Surveys and Stormwater Runoff Monitoring
3. Water Quality and Pollutant Loading Analysis
4. Land Use and Nonpoint Source Loading Analysis
5. Mass Balance Analysis
6. Water Quality Impact Analysis
7. Sensitivity Analysis
8. Control Plan Development

The methodology incorporates three overall classes of technical activities: problem analysis, source analysis, and identification of potential control measures. Problem analysis and source analysis are performed concurrently throughout most of the methodology.


INVENTORY AND EVALUATION OF EXISTING DATA (1)
FIELD SURVEYS AND NONPOINT SOURCE MONITORING (2)
IN-STREAM WATER QUALITY AND POLLUTANT LOADING ANALYSIS (3)
SELECTION OF SUBAREA
SELECTION OF LAND USE CATEGORIES (4)
MASS BALANCE ANALYSIS (5)
WATER QUALITY IMPACT ANALYSIS (6)
SENSITIVITY ANALYSIS (7)
CONTROL PLAN DEVELOPMENT (8)

Note: Arrows indicate major flow paths of analyses

Source: Betz Environmental Engineers, Inc.

FIGURE 1

SCHEMATIC OF GENERAL METHODOLOGY

B. INVENTORY AND EVALUATION OF EXISTING DATA

Primary and secondary sources of data should be collected and evaluated. The type of data to be collected, how the data are to be used, and sources of data are summarized in Table 1. Specific data requirements are summarized below.

1. Water Quality and Biological Data

Long-term water quality records and storm-related water quality data should be obtained. Long term water quality data indicate seasonal and historical trends associated, in general, with steady-state conditions. Storm data, if available, will indicate the existence of transient water quality problems associated with stormwater runoff. Comparison of long-term and storm-related water quality data indicates the relative impact of nonpoint sources. Existing water quality should be compared to water quality standards and the violations noted.

An important point to consider is that the investigation of problem areas should include more than chemical analysis of water quality. Existing biological data should be evaluated along with water quality data. Biological communities are not as transient as water quality and, as such, are excellent indicators of problem areas. This is particularly important because most past environmental studies were performed during dry weather conditions when the impact of nonpoint sources were not readily apparent from water quality data. However, the sessile or fixed nature of many aquatic organisms provides a measure of the long-term impact of nonpoint sources. This is especially true of benthic organisms such as macroinvertebrates. Thus, biological data on algae, fish, and benthic macroinvertebrates should be evaluated to identify existing or potential problem areas.

The evaluation of water quality and biological data is the first step in problem analysis.* It is a preliminary analysis because, in most cases, the existing data are not

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* Procedures and criteria for assessing water quality impacts and resulting impacts to biota can be found in the EPA publication, "Area Wide Assessment Procedure Manual," Volume I, No. EPA-600/9-76-014, July 1976, Chapter II, Data Base Inventory and Problem Identification.

TABLE 1

SUMMARY OF DATA NEEDS FOR THE GENERAL METHODOLOGY TASKS

Type of Data	Input to Task No.	How The Data Is To Be Used	Potential Data Sources
Water Quality and Biological	3 & 7	Identify types of pollution Locate problem areas Preparation of pollutographs Calibrate and verify mass balance	Local and state water pollution control agencies, USGS stream records, EPA (STORET) records
Rainfall	3	Prepare unit hydrographs and pollutographs Determine R factor in mass balance calibration and verification	U.S. Weather Service records (NOAH)
Streamflow Records	3	Prepare unit hydrographs and pollutographs Calibrate and verify mass balance Determine seasonal and storm variations	Local, state and federal flood control agencies; USGS streamflow records
Pollutograph and Runoff	3 & 4	Calibrate and verify mass balance	Existing local and state reports; USGS records
Land Use	4 & 8	Identify existing nonpoint source Identify nonpoint source controls Calibrate and verify mass balance (K, P and K2 factors)	Local, regional and state planning agencies, USGS aerial and satellite mapping program. General literature on nonpoint source loadings
Typography and Soils	4	Determine K and LS factors in mass balance	County soil survey reports and U.S. Soil Conservation Service reports
Nonpoint Source Control	4 & 8	Determine the P and K2 factors in mass balances Input to alt. control ranking Input to Better Management Practices ranking	Local and regional zoning ordinances; county and state highway construction regulations, state and federal regulations on soil erosion and sediment control; general literature
Other	4 & 8	Inventory typical nonpoint source loading ranges Inventory typical nonpoint control measures	General literature; journals and publications; state and federal regulations

sufficient for a comprehensive identification of the problem. Nonpoint source water quality problems can be either transient or steady-state.

Transient problems occur on a localized basis with a time frame of hours to days. Transient water quality parameters usually include stream flow, floatables, bacteria, virus, suspended solids and dissolved oxygen. These parameters usually cause localized problems during and right after a storm for periods ranging from hours to days.

Steady-state problems occur on a regional or basin basis with a time frame ranging from weeks to years. Steady-state water quality parameters usually include nutrients, dissolved solids, metals, herbicides and pesticides. These parameters usually cause regional problems well after a storm during low to medium stream flow conditions. A good example of a steady-state problem is eutrophication caused by nutrients generated by nonpoint sources during the wet season, but occurring during the dry, low flow warm weather season.

Existing data should be reviewed to determine whether the water quality problems are transient, steady-state or both. The problem parameters and their probable source should also be identified.

2. Rainfall Data

Rainfall records corresponding to the stormwater quality data are required in order to develop unit hydrographs of stream flow and pollutographs of stream loadings during storms. These analyses provide an important insight into the cause-and-effect relationships between storms and water quality, thus enabling the determination of a rainfall factor (R) to be used in calculating the annual nonpoint source loading. Other analyses which may be performed with these data include sensitivity analyses relating water quality to storm intensity, storm magnitude or accumulation intervals between storm events.

3. Streamflow Records

Records of streamflow corresponding to those of water quality and rainfall are also necessary for the completion of unit hydrographs and pollutographs. As with rainfall, sensitivity analyses can be performed to relate water quality to stream flow.

4. Pollutograph and Runoff Data

Stormwater runoff data specific to the study area should be obtained. If the data are not available from past studies, field monitoring of select storms should be performed. If possible, at least two storms should be monitored for each major land use category in the study area. National or regional nonpoint source runoff data should be used only if field monitoring cannot be performed. Stormwater runoff data are necessary for (1) the calculation of the total annual pollutant loading, and (2) the determination of pollutant loading rates for specific land uses.

5. Land Use Data

Land use data specific to the study area should be obtained for the following purposes: (1) to provide a basis for the logical division of the study area into sub-areas, (2) to provide a basis for calculating annual nonpoint source pollutant generation from land use loading factors, and (3) to facilitate the development of control plans for the study area.

6. Topography and Soils Data

Calculation of site specific runoff loading factors requires localized topography and soils data such as soil association maps, critical slope maps, and drainage density maps. These maps can be readily developed from USGS topographical maps, aerial photographs, and SCS soil survey data.

7. Nonpoint Source Control Data

Natural or man-made nonpoint source controls applicable to the study area should be identified and their pollutant removal efficiency and cost effectiveness evaluated. If existing nonpoint source controls are not available in the study area, general literature values can be used.

C. FIELD SURVEYS AND NONPOINT SOURCE MONITORING

1. Field Surveys

Field surveys are a key element in the methodology and should be performed to identify land use trends, specific areas of development and construction, drainage characteristics, unrecorded sources of pollution, problem areas, and potential monitoring sites. Reliance on USGS topographical maps, land use maps, and aerial photographs can be misleading.

The field surveys should be designed to incorporate the following activities:

- Investigation of specific problem areas identified from the evaluation of existing water quality and biological data
- Investigation of areas undergoing development and construction
- Investigation of unrecorded point sources or significant nonpoint sources (e.g., industrial and commercial sites with oil spills, refuse and byproduct piles, and junk storage areas)
- Investigation of areas experiencing stream modifications and erosion
- Investigation of man-made drainage systems that alter natural drainage characteristics and bypass natural buffer zones
- Investigation of general land use trends, primarily of development near streams, and topographic features of the land (slope, soil type, etc.)
- Investigation of study area stream conditions during or immediately after a rain event to ascertain and correlate pollution problems with runoff loads (e.g., stream biota, sediment deposits, scouring and evidence of land erosion)

The field surveys are performed to provide data for both problem analysis and source analysis. In addition, the information obtained from the field surveys is used to develop and evaluate nonpoint source controls. Site specific knowledge of the study area is important when considering the potential effectiveness and suitability of selected controls.

The level of detail of the field survey will depend on (1) economic and personnel constraints, (2) time constraints, and (3) the size of the study area. For a large study area, a limited number of representative sites should be selected for investigation based on review of the existing water quality, biological, land use, and storm runoff data.

Detailed notes and photographs should be taken during the field surveys. Salient observations made during the field surveys should be transferred to maps of the study area for use in dividing the study area into subareas and for other applications in the methodology.

2. Nonpoint Source Monitoring

Nonpoint source monitoring should consist of two types: direct land use runoff monitoring and in-stream stormwater monitoring. Direct runoff monitoring consists of sampling runoff from typical land use areas to determine pollutant loading factors specific to land use type. These factors are used in a modified universal soil loss equation to generate nonpoint source loadings.

The stormwater runoff or storm sewer monitoring data are land use specific and are used to determine land use loading factors, whereas in-stream stormwater monitoring is not usually definitive enough to sort out specific land use loading factors. The in-stream stormwater data are used to formulate a relationship between total stream loading and rainfall.

The in-stream stormwater monitoring should be performed during and after storms at selected summation points in the study area. Summation points are stream locations selected using the following criteria: (1) maximum amount of water quality data are available, (2) stream sites are located at the downstream end of the study area, and (3) division of the study area into subareas logically revolves around the summation points (i.e, the summation point should be the pivot for various subareas; it should not be included in only one subarea). Subareas and summation points are described on page 18. The observed in-stream water quality at each summation point will be used to calibrate the computed nonpoint source loading, calculated from land use loadings (this mass balance approach is described in detail further on in the methodology).

D. WATER QUALITY AND POLLUTANT LOADING ANALYSIS

The mass balance analysis is used to compare the total in-stream pollutant loading (calculated by monitoring in-stream dry and wet weather conditions) to the in-stream nonpoint source loading (calculated by applying pollutant loading factors to the land uses in the study area). The land use specific loading factors are then calibrated to provide agreement between the calculated nonpoint source loading based on land use factors and the measured in-stream nonpoint source loading.

In calculating the total annual pollutant loading, the total in-stream loading at a given summation point consists of point source loadings, nonpoint source loadings and background stream loadings. The in-stream nonpoint source loading is calculated as shown below:

$$\begin{array}{c}\text{Total Annual}\\ \text{In-stream}\\ \text{Nonpoint Source}\\ \text{Loading}\end{array} = \begin{array}{c}\text{Total}\\ \text{Annual}\\ \text{Storm}\\ \text{Loading}\end{array} - \begin{array}{c}\text{Point}\\ \text{Source}\\ \text{Loading}\end{array} - \begin{array}{c}\text{Background}\\ \text{Loading}\end{array}$$

Total annual storm loading can be calculated by monitoring in-stream water quality at a summation point during a few storm events and approximating the nonpoint source loading to an annual loading based on annual rainfall as shown in the following equation:

$$\text{Total Storm Loading} = \text{Average Storm Loading} \left[\frac{\text{lbs}}{\text{inch of rainfall}}\right] \times \text{Annual Rainfall (inches)}$$

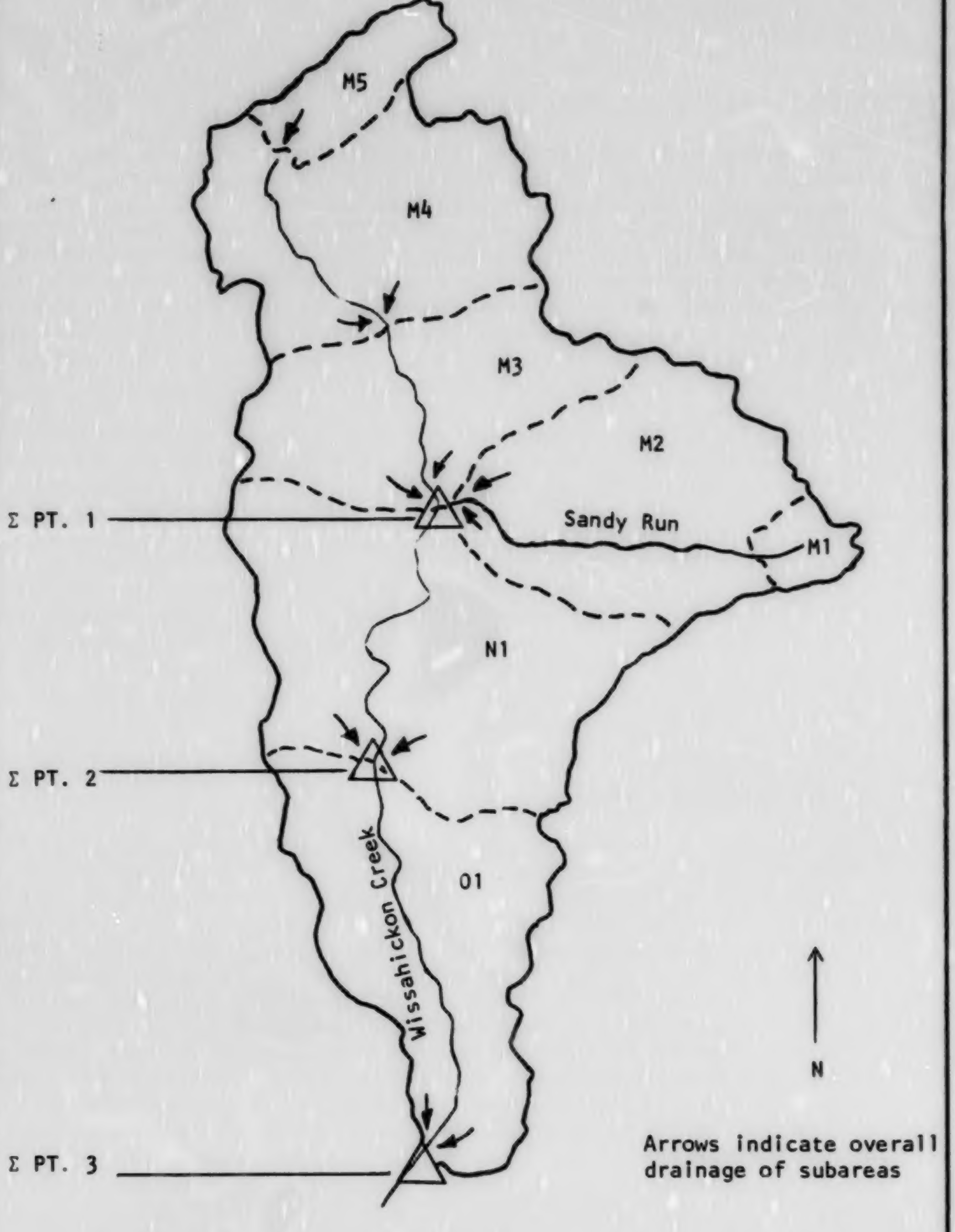
All storms do not yield the same nonpoint loads. The loading depends on the storm intensity, duration and the time between storms for land pollutants to accumulate. However, if there are sufficient rainfall data and storm monitoring, average storm loadings and annual loadings can be determined. The methodology for accomplishing this is illustrated in the application of the case study under "Water Quality and Pollutant Loading Analysis."

E. SELECTION OF SUBAREAS AND LAND USE CATEGORIES

The watershed must be divided into subareas. The subareas should correspond to hydrological drainage areas which are selected to offer adequate illustration of nonpoint source loadings and stream loading effects. Figure 2 illustrates a typical division of a basin into subareas showing receiving stream and selected summation points. The appropriate selection of subarea boundaries is critical in its effect on derived sediment yield. A variety of approaches can be applied and the net evaluation of land use impacts on water quality is variable, depending on subarea boundaries. Nevertheless, the magnitude of variance among most approaches should not be so significant that it skews the results beyond usefulness.

The following factors should be considered in selecting subareas:

1. Hydrologic characteristics
2. Man-made impacts on natural drainage
3. Land development patterns
4. Common land uses
5. Municipal and hydrologic boundary coincidence
6. Drainage into selected summation points


M5
M4
M3
M2
Σ PT. 1
Sandy Run
M1
N1
Σ PT. 2
Wissahickon Creek
01
N
Σ PT. 3

Arrows indicate overall drainage of subareas

FIGURE 2

WISSAHICKON WATERSHED SUB-AREA SEGMENTATION

Source: Betz Environmental Engineers, Inc.

1. Hydrologic Characteristics

The hydrologic characteristics of the study area, including natural drainage areas, major tributaries, and ridge lines, should be considered in delineating subareas. All significant tributaries and ridge lines which frame these tributaries should also be included. A significant tributary is one for which either water quality data have been collected and are available, or one which is tributary to an urbanizing or sub-urbanizing land corridor. Also to be considered are tributary branches which traverse land predominated by a major land use such as silviculture or mining.

An intuitive assessment of the relative significance of a tributary in defining subareas is possible by weighing the relative impact of loadings to the tributary, using data collected at the nearest nonpoint load summation point in the mass balance model, the average distance to the summation point from points along the tributary, and the proximity of more intensive land uses to the tributary. If the tributary drains no immediate land uses of the type generating higher nonpoint pollution loads and if the tributary is a minor channel far removed from a summation point, its overall usefulness as a criterion for defining a subarea is questionable.

2. Man-made Impacts on Natural Drainage

The previous task of assessing hydrologic characteristics must be qualified by the existence and effects of in-ground stormwater collection and conveyance systems as well as above-ground channelization, impoundments, dams, and other man-made water resource facilities that affect containment, direction, and flow of runoff. This qualification is important in the delineation of subareas as well as in the overall comprehension of land use-water quality relationships. Man-made conveyance systems generally have been built to fit natural drainage features; nevertheless, these systems dramatically alter the natural drainage characteristics of an area and should be considered in the selection of subareas.

3. Land Development Patterns

Subarea delineation also involves the identification of development patterns such as standard street grid patterns, cluster development providing higher densities with high proportions of open space, central business districts, and shopping malls. Each of these development schemes are commonly associated with community planning techniques of various eras. Turn-of-the-century planning featured the "City Beautiful Movement," characterized by broad boulevards, major civic facilities, and urban park systems. The case study in this handbook accounted for the effects of Fairmount Park in Northeast Philadelphia in the selection of subareas. This famous development style had a strong influence on the overall development pattern and is a prime example of using readily available knowledge of regional development patterns, coupled with an understanding of urban planning milestones, to clarify subarea characteristics.

4. Common Land Uses

The sediment yield effects of common, contiguous land uses are more evident if associated with the same subareas. Consideration should be given to those land uses that are similar and contiguous but which lie in different drainage areas. A decision must be made whether they should be combined in one subarea regardless of drainage, or separated into two or more subareas. Clearly, the effect of drawing the subarea around the contiguous land area would be to show a more significant raw yield from that area, particularly for urban and agricultural areas. Where all such land lies in one municipality, it may be sensible to follow this approach because the analysis of nonpoint source controls is simpler if the land lies entirely in one municipality. The primary goal is to delineate subareas so as not to lose or mask information that may be desired at future stages of the methodology. While the strict hydrologic approach is conceptually valid, it is void of the practical considerations associated with the response of local government to nonpoint source control.

5. Municipal and Hydrologic Boundary Coincidence

There is a practical value to using municipal boundaries as subarea boundaries, in that most control programs are organized on a municipal basis. In some cases, however, natural features such as ridge lines may be chosen as subarea boundaries. The practical value of using natural features as boundaries is that the hydrologic system is more accurately defined for the analysis. In some cases, a ridge line may even serve as a municipal border. In general, however, having municipalities wholly contained in a subarea is more appropriate for this methodology. The one exception is that summation points must reflect total drainage of all subareas above it such that the measured nonpoint loads at these points accurately reflect the impact of contributing land uses.

6. Selection of Land Use Categories

After subarea delineation is complete, the next step is to map the study area by land use categories and measure acreage of each land use group in each subarea. The specific land use categories to be mapped depend on (1) the dominant land uses in the study area, (2) the level of detail required or desired in the analysis, and (3) the availability of specific storm runoff data for each land use. Runoff data may be available from previous studies, literature sources, or monitoring performed during the study. The rationale for land use category selection is addressed on page 100 of the case study.

The tasks of mapping and calculating acreage are standard procedures common to all planning agencies. Consequently, this task will not be expanded upon in this section. An explanation of the mapping and calculation procedures as applied in the Lower Wissahickon Case Study is found in the technical appendix accompanying that study.

F. DETERMINATION OF RAW LOADING RATE

Pollutant loading rates should be calculated for each land use in the study area. These loading factors can be obtained from literature values or from the direct runoff monitoring described later in this report. The sediment loading function is based on concepts of the mechanisms of gross erosion and sediment delivery. These loading factors are in reality net loading rates for a specific land use with unique characteristics such as soil properties, slope conditions, land cover conditions, and conservation practices. The loading factor developed from a specific site for a given land use category should not be applied directly to other similar land use areas. Land use modifications based on the universal soil loss equation should be used to allow a site-specific application of the loading factor. This concept is based on principles illustrated in the universal soil loss equation.

Information pertaining to soil classifications, slope conditions, etc. are required to use the universal soil loss equation. The present methodology uses a modified soil loss equation as described below*:

$$Y(S)E = \sum_{i=1}^{n} AiKi\ (R \cdot LS \cdot SD \cdot P \cdot K2)i$$

where:

Y(S)E is the sediment loading in lbs/year
A is the area of the subarea in acres
K is the average annual raw runoff rate from the land use in terms of lbs/acre/yr
i is the type of land use
R is the rainfall factor expressing the ratio of annual rainfall intensity to the rainfall intensity of the calibration year
LS is the slope length/steepness factor which reflects increased sediment detachment and transport as runoff velocities and volume increase with increased slope length

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* A complete description of the universal soil loss equation can be found in the publication "Soil Erosion: Prediction and Control," Soil Conservation Society of America, 1977, and "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," McElroy et al, EPA-600/2-76-151, May 1976.

SD is the sediment delivery ratio which reflects the fraction of sediment runoff from upland sources actually reaching a contiguous stream. Factors such as proximity to stream, soil characteristics (porosity, water table, etc.) and availability of deposition areas affect the sediment delivery ratio

P is the erosion control factor for natural sediment control practices such as buffer strips around streams and wetlands which act as a sink to sediment and other pollutants

K2 is the erosion control factor for man-made controls such as regulatory and physical controls

In the modified soil loss equation, the factors R, LS, SD, P and K2 are modifiers that relate the raw loading rate to the net loading rate reaching the stream. The raw loading rate expresses the raw erosion of sediment from the land, while the net loading rate is the reduced erosion reaching drainage ditches or streams as a result of being reduced by modifiers. Since the term (R·LS·SD·P·K2) will always be less than unity, the net loading will always be lower than the raw loading.

Based on the above principles, the loading rate measured for a specific land use during the monitoring program is actually a net loading rate that is site-specific for a particular land use. To apply this loading rate to other similar land uses, the raw loading rate must be calculated.

This calculation consists of applying the land use modification (factors) to the net loading rate.

The general methodology for calculating raw loading rates for each land use category is presented below:

- Monitor direct stormwater runoff from a site representing a specific land use.
- Calculate the net loading rate for the specific site in terms of lbs/acre/yr or other suitable units.

- Based on site-specific characteristics of the area, calculate modifier factors, R, L, S, SD, P and K2.

- Using the modifiers, calculate the raw loading rate as follows:

$$\text{Raw Loading Rate} = \frac{\text{Net (Measured) Loading Rate}}{R \cdot LS \cdot SD \cdot P \cdot K2}$$

The raw loading rate can now be directly applied to other similar land uses in the study area. The procedure above should be followed for each typical land use in the study area. If runoff rates from typical land uses are not available, literature loading values may be used.* Care must be taken to assure that the literature values represent runoff from similar soil characteristics, land use activities and climatic conditions.

Not all pollutant runoff is sediment-borne (associated with sediment particles); some pollutants are soluble (dissolved in water). The Four Mile Creek-Occoquan study, (Northern Virginia Planning District Commission, October 1976), noted that as much as 50 percent of runoff nitrogen and phosphorus was in soluble form for some land uses. Therefore, there are some inherent inaccuracies in the use of KN ratios for these pollutants. However, since at least 50 percent is sediment-borne, this approach can yield a fair approximation of pollutant loads without resorting to an expensive independent analysis of each pollutant.

The above procedure is performed for the sediment loading. Other parameters are related to the sediment loading by a factor Kn relating the concentration of a particular parameter (nutrient, metal, etc.) to that of sediment for each land use. The loading for a particular parameter is calculated as follows:

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* Typical pollutant runoff rates can be found in referenced items 12, 18, 19, 21, 38 and 39 listed in the bibliography.

$$Y(S)N = \sum_{i=1} K1_{(i)} \cdot KN_{(i)}$$

where:

$Y(S)N$ is the pollutant loading rate for parameters (N) in lbs/acre/yr

$K1_{(i)}$ is the net sediment loading for land use (i) determined previously $(A \cdot K \cdot R \cdot LS \cdot SD \cdot P \cdot K2)_i$

$KN_{(i)}$ is the ratio of the loading rate of pollutant (N) to the loading rate of sediment for the land use (i)

The parametric ratios, KN, for each typical land use can be determined by field monitoring of land use stormwater runoff or from literature values of similar land uses.

G. DETERMINATION OF RAW LOADING RATE MODIFIERS

The simplified universal soil loss equation employs several modifying factors to the basic raw runoff loading rate (K factor). These are:

Rainfall Factor - R
Slope Length - LS
Sediment Delivery Ratio - SD
Natural Control Factor - P
Other Pollutant Ratios - KN
Best Management Control Factors - K2

1. Rainfall Factor - R

The rainfall factor is used to determine the effect of storm frequency and intensity on sediment erosion from pervious land and on scour and runoff of pollutants from urban areas.

The mass balance model is empirically calibrated to the rainfall intensity for the calibration (control) year. It is modified for rainfall/intensity for subsequent years and alternative iterations.

The rainfall factor for subsequent years can be determined by: (1) using the ratio of rainfalls of the subsequent years to that of the control year, or (2) using the ratio of total annual flow (cfs-days) of the subsequent years to that of the control year. A high degree of success was attained using both methods in the case study. Calculations of nonpoint loads in the case study showed an error of 10% using the ratio of total annual rainfall and an error of 4.3% using total annual streamflow ratios. Both errors are within acceptable limits; neither represents a preferred method. The higher error obtained by using the rainfall ratio probably resulted because the rainfall ratios were based on records obtained from a basin adjacent to the study area. Stream flow ratios were based on flow measurements taken within the study area.

The "R" factor for the rainfall method is simply expressed as:

$$R = \frac{\text{Total Rainfall of Year Under Consideration}}{\text{Total Rainfall of Calibration Year}}$$

Some error is implicit in determining this ratio in that not all of the rainfall occurs during storms. Nevertheless, in the case study more than 75% of the rainfall in excess of 0.5 inches per day occurred during storms.

Similarly, the "R" factor for the total annual flow method is simply expressed as:

$$R = \frac{\text{Total Flow (cfs-days) of Year Under Consideration}}{\text{Total Flow (cfs-days) of Calibration Year}}$$

Again, there is a slight implicit error in that not all of the flow results from storm events. Nevertheless, the storm flow in the case study for rainfalls in excess of 0.5 inches per day accounted for greater than 60% of the total flow.

2. Slope Length - LS

This factor describes the effect of steep slopes and the run lengths of these slopes. The detailed data needs and analyses required in the universal soil loss equation were simplified in this methodology. A simplified averaging approach was developed as follows:

(A) Topographic maps of the area are examined and the land area is apportioned into several slope ranges. For example, a study area could be divided into three slope characteristics:

  (1) Those areas on slopes less than 4 percent grade

  (2) Those areas on slopes between 4 percent grade and 8 percent grade

  (3) Those areas on slopes greater than 8 percent

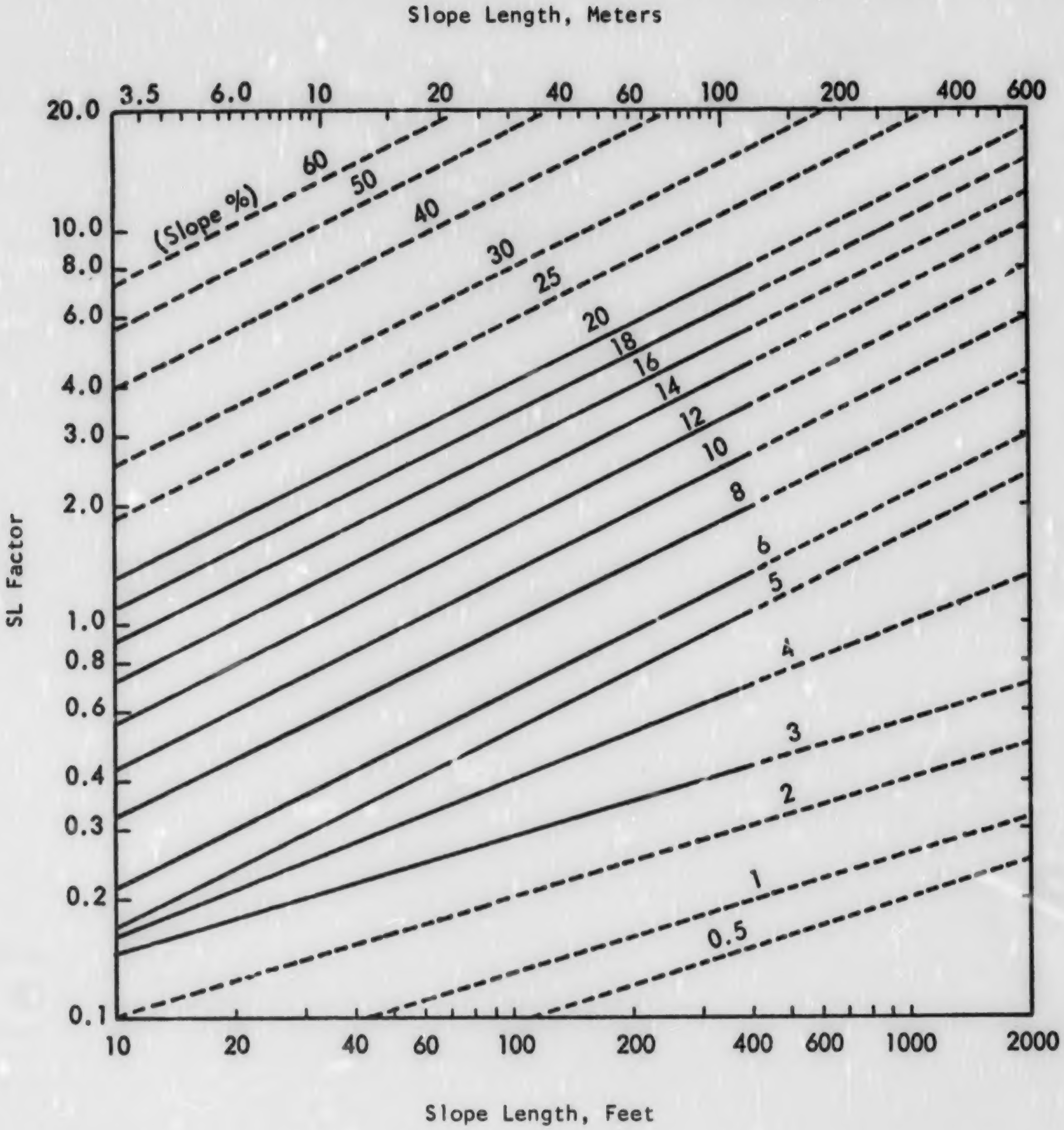
(B) The land use areas outlined on topographic maps are then examined and characteristic run lengths of slopes are determined. For example, it might be found that:

  (1) Slopes of less than 4 percent grade exhibited an average run length of 2000 feet

  (2) Slopes between 4 percent and 8 percent exhibited an average run length of 1000 feet

  (3) Slopes greater than 8 percent exhibited an average run length of 200 feet

(C) Using the slope-lengths determined from steps 1 and 2, and the criteria presented in Figure 3, the slope length (SL) factor is determined for each land use. For land use areas overlapping two or more characteristic slope-lengths, a weight averaged factor must be determined.



The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available.

FIGURE 3

SLOPE LENGTH DETERMINATION CRITERIA

Source: EPA, 1976

$$SL_{(1)} = \frac{SL_{(mild)} \times A_{(mild)} + SL_{(mid)} \times A_{(mid)} + SL_{(steep)} \times A_{(steep)}}{A_{(1)}}$$

where:

$SL_{(1)}$ = weight averaged slope length for land use (1)

$SL_{(mild)}$ = slope length factor for mild slopes (less than 4%)

$SL_{(mid)}$ = slope length factor for mid range slopes (4% to 8%)

$SL_{(steep)}$ = slope length factor for steep slopes (greater than 8%)

A = area

See the case study application of slope-length determination in Section IV for a detailed explanation of the application criteria.

3. Sediment Delivery Ratio - SD

This ratio expresses the percentage of eroded sediment that reaches a stream or drainage ditch. Two factors influence sediment erosion: (1) the ability of the soil to absorb water and retard the movement of sediment expressed as the runoff potential of the land use area, and (2) the distance or proximity of the eroded sediment to streams or drainage ditches, expressed as the drainage density of the land use area.

(A) Runoff Potential: The runoff potential of the land can be determined by the use of hydrologic groups, categories of soil type designated by the Soil Conservation Service. All the known soil series are divided into four classes of runoff potential (low, moderately low, moderately high and high) based on infiltration rate and transmission rate. Infiltration rate is defined as the rate at which water enters the soil at the surface; the rate is controlled by surface conditions. Transmission rate is the rate at which the water moves in the soil; the rate is controlled by soil horizons. Pertinent soil properties are particle size composition, depth of seasonally high water table, permeability after prolonged wetting, and depth to impermeable layer. All classifications are based on conditions of prior wetting, opportunity for swelling and the absence of protective vegetation.

The soil types which make up a particular area can be found in county soil surveys which are produced by the U.S. Department of Agriculture, Soil Conservation Service (SCS). These surveys describe the soil series found in the county and map their location. Using the nation-wide master list of hydrologic groups, the runoff potential of each soil series can be determined and a map produced showing runoff potential within the study area.

The soil surveys are available for most of the country from county-based SCS offices. The master Hydrologic Group listing can be found in "Hydrologic Guide for Use in Watershed Planning," National Engineering Handbook, Section 4, Hydrology, Supplement A, USDA, Soil Conservation Service, 1964. For example, a runoff potential map for the Wissahickon Watershed was produced to determine the percentage of land in each hydrologic group and to identify problem areas. A soil map was compiled using the Montgomery County Soil Survey (1967) and the Bucks and Philadelphia Counties Soil Survey (1975). The soil series found in the area are then categorized into hydrologic groups using the nation-wide master list.

If a locally-named soil series does not appear in the list, a local list can be consulted, or if such a publication is not available, the soil type can be compared with characteristics of soils included on the master list, and its relative position can be determined. A map overlay is then produced with four categories: (a) moderately low, (b) moderately high, (c) high runoff potential and (d) urban or man-made land. This latter category consists primarily of impervious surface and thus can also be considered as having high runoff potential.

(B) Drainage Density Determination: A brief literature and data search should be made to ascertain whether any previous investigations have provided information on drainage density within the basin. Such sources as USGS water resources surveys and local geologic surveys should be consulted. If drainage density data are not available, drainage density can be calculated as follows:

1. Using topographic maps, measure length of stream miles, drainage ditches and storm sewer lines

2. Calculate drainage density of each subarea as:

$$\text{Drainage Density} = \frac{\text{Miles of Drainage}}{\text{Area of Drainage (Mi}^2\text{)}} = \frac{1}{\text{miles}}$$

C. Sediment Delivery Determination: Three steps are used to determine sediment delivery:

(A) Land use overlays are superimposed on the hydrologic overlays, and areas within each hydrologic soil condition are determined (A_A through A_D for hydrologic groups A through D).

(B) Using the criteria shown in Figure 3, determine the sediment delivery ratio of each hydrologic grouping for each subarea drainage, and summarize results in a table (SD_A through SD_D for hydrologic groups A through D in each subarea).

(C) Calculate the sediment delivery ratio of each subarea/land use as follows:

$$SD_{\text{(land use)}} = \frac{A_{(A)} \text{x} SD_{(A)} + A_{(B)} \text{x} SD_{(B)} \text{x} A_{(C)} \text{x} SD_{(C)} + A_{(D)} \text{x} SD_{(D)}}{\text{Total land use area within subarea}}$$

Some simplifications may be employed. In the case study a relatively narrow range of drainage densities existed; therefore, a single drainage density was employed for all subareas. See the case study for more details on application of sediment delivery ratio criteria.

4. Natural Control Factor - P

This factor expresses the reduction of sediment delivered to the stream as a function of natural controls, i.e., flood plain buffer strips or natural storage areas such as wetlands. In the case study, buffer strips surrounded many of the major streams; however, the buffer strips were usually bypassed by storm sewer lines that drained urban areas directly to the streams. This bypassing of buffer strips must be accounted for in the P factor.

The buffer strip reduction of sediment loads is determined by:

- Mapping an overlay showing significant buffer strips surrounding receiving streams and superimposing the buffer strip overlay on the land use map.
- Each land use category within each subarea is examined to determine the relative order of magnitude of the buffer effect:
- Wide buffer between land use and stream - Maximum effect
- Medium buffer between land use and stream - Medium effect
- Narrow buffer between land use and stream - Minimum effect
- The retardation effect of sediment delivery is estimated for each buffer strip classification: wide, medium, narrow.
- The buffer strip bypass factor (KB) is estimated for each land use in each subarea. This factor is a function of the estimated fraction of load from the land use area that is not bypassed directly to streams. It is estimated for each land use and represents the fraction of the sediment load that is subjected to buffer strip retardation.

The P factor is calculated for each land use as follows:

$$P = (1 - KA \times KB)$$

where:

P = fraction of load delivered to stream
KA = fraction of load retarded due to buffer strip
KB = fraction of load received (unbypassed) by buffer strip.

The P factor determined in step 5 should be modified by the estimated action of natural detention basins. Swamps, wetlands and surrounding streams act as detention basins and will retard sediment delivery to streams. The P factor is multiplied by the estimated reduction due to natural detention to arrive at the final P factor. See the case study for more details on the application of the natural control factors (P).

5. Other Pollutant Ratios - KN

The KN ratio provides a means of determining pollutants loads other than sediment, e.g., BOD, nitrogen, phosphorus, heavy metals. They are simply expressed as a fraction of the sediment load. They are determined empirically from measured land runoff pollutants. There are inherent inaccuracies in this method in that not all transport of nonpoint pollutants are sediment borne. Some nonpoint pollutants are in soluble form; however, with adequate monitoring of pollutants from typical land uses, a KN ratio can be determined which reflects total pollutant of both soluble and insoluble forms.

Sediment concentrations typically peak sooner than other pollutants such as phosphorus and nitrogen. Therefore, ratios of pollutant *concentrations* to sediment concentrations should *not* be used as a measure of the fraction of pollutant load delivered because this value will vary in time after a storm and the results may be misleading. Only the ratio of pollutant *loadings* should be used to calculate KN.

Pollutant loadings are calculated as a flow-concentration product of the area under the hydrograph (flow curve) and the corresponding pollution concentration curve.

The KN ratio for each specific land use within each subarea is estimated using the average land use KN ratios as a guide. For instance, if the average phosphorus KN ratio for an urbanized area was 0.001, and the urban land under consideration is populated to approximately 75% of that of the average urban area, the phosphorus KN ratio for the particular land use would be (0.75 x .001) or 0.0075.

H. LAND MANAGEMENT CONTROLS

In this methodology, land management control is a general term which includes municipal regulatory controls, maintenance controls, and physical controls. It is important to assess the meaning of "control" in this context. Control in land development management has historically implied a responsibility of government, generally on the municipal level, to regulate the activities of developers and builders to ensure conformance with community standards and goals. In this context, the control most often has been an ordinance, regulation, or local law which carries with it local responsibility for monitoring and enforcement. Such controls are herein referred to as "municipal regulatory controls." They must necessarily be differentiated from what will be termed "maintenance controls" and "physical controls." In this study, the primary interest is in the provisions of the land management controls which address runoff from land.

1. Maintenance Controls

Maintenance controls are required for existing developed sites and new land development sites. For developed sites, maintenance controls are required where sediment generation results from the renovation or alteration of existing sites (building alteration, road repair or widening, and other structural improvements) as well as from the common daily accumulation of debris, litter, and dirt. For new land development, maintenance controls are applied primarily as a precautionary measure to contain building materials, scraps, and other wastes. These controls are actual activities involving labor and machine intensive work in possible conjunction with physical facilities or structures (for further information on maintenance controls, see pp. 44-45). The application of this methodology for the case study incorporated three areas of maintenance controls:

Neighborhood sanitation
Maintenance of on-lot disposal systems
Collection system controls

2. Physical Controls

Physical controls involve structural measures which interface with natural stormwater runoff to reduce the effective pollutant load. For construction activities, this would involve control of storm-generated runoff, erosion, sedimentation and subsurface infiltration.

Table 2 illustrates a variety of physical controls which are typically considered to satisfy some of the following objectives of a pollution control program applied to construction activities:

(A) Protection of exposed ground cover to minimize erosion and soil loss

(B) Control of the velocity of stormwater runoff to maximize natural infiltration, minimize ground cover and stream bank erosion, and to inhibit downstream flooding

(C) Promotion of natural infiltration of runoff and natural filtration of sediment and associated pollutants

(D) Containment of sediment and associated pollutants on-site

(E) Containment of stormwater runoff on-site for either retention, detention, or velocity control

Many of the controls listed in Table 2 appear to serve multiple objectives. For instance, mulches, nets, and

TABLE 2

PHYSICAL CONTROL PRACTICES FOR CONSTRUCTION ACTIVITIES

	Protection of Exposed Ground	Runoff Velocity Control	Filtering of Sediment & Infiltration	Containment of Sediment	Containment of Runoff
Channel walls and linings	●				
Chemical soil binders	●				
Culvert risers			●		●
Dams and reservoirs				●	●
Detention basins		●	●	●	●
Ditches and swales	●	●			
Diversion terraces	●	●			
Downdrains	●				
Filter berms	●	●	●		
Grade stabilization structures	●				
Infiltration basins		●	●		●
Inlets		●	●		
Interceptor channels	●	●			
Level spreaders		●			
Mulches	●		●		
Nets	●		●		
Previous blankets	●		●		
Ponds				●	●
Porous pavements			●		
Retention basins		●		●	●
Riprapping	●	●			
Rooftop detention		●			●
Sandbag or straw bale barriers		●	●	●	
Sedimentation basins				●	●
Seepage pits					●
Sodding	●				
Spillways	●	●			

Note: Most of these control practices may be applied selectively to new construction sites as well as existing development under maintenance, renovation, or alteration.

pervious blankets, aside from protecting exposed ground from erosion, also serve to encourage natural water infiltration on-site. It is also significant that many of the physical controls listed require some form of maintenance control. The best illustrations of this are catch basins and sedimentation basins which require regular maintenance.

The physical controls listed in Table 2 can be explicitly required or implicitly required by stipulating performance goals in a municipal ordinance, law, or regulation. In applying controls within this methodology, attention has been placed on municipal regulatory controls and supportive enforcement mechanisms. A list of municipal regulatory controls and potential maintenance controls are included in Appendix F. The former list contains the ordinances, laws and regulations considered in the case study of the Lower Wissahickon Watershed.

5. Inventory of Existing Land Management Controls

At this stage, the methodology should focus on four primary objectives:

(A) Identify applicable land management controls on new and existing land development which might have beneficial water quality effects, regardless of their current application in the study area.

(B) Identify land management controls currently imposed by regulatory agencies in the study area. This should be done for both new land development and existing development.

(C) Assess the "relative" effectiveness of the potential land management controls on reducing sediment delivery from new land development sites and existing, but renovated, sites.

(D) Assess the relative effectiveness of the land management programs of regulatory agencies as currently imposed on new land development and existing, but renovated, development. A management program is the total combination of land management controls in force in a municipality.

As the objectives imply, an important distinction in this methodology is drawn between sediment generation from new land development and sediment generation from existing development with on-going maintenance and renovation. New land development commonly involves a significant tract of undeveloped or formerly agricultural land (minimum 2 acres) which will be developed to accommodate a new, more intensive use (i.e., residential/industrial/commercial). Sediment generation occurs primarily as a result of soil cover removal and topsoil disruption. Existing land development, on the other hand, accounts for a much larger proportion of total land. It is assumed that sections of each study area and each subarea were developed at different times. Further, it is assumed that the older areas require an on-going schedule of maintenance, renovation and alteration, with newer sections entering this cycle in years to come. The total picture becomes one of continual maintenance, renovation, and alteration in the study area.

While emphasis in the literature has been mostly on the significant generation of sediment and other pollutants from new land development, it is the intent of this methodology to qualify this emphasis by directing attention to the sediment-generating capacity of existing land development. The case example of the Lower Wissahickon Watershed is one in which this approach is applied to a study area with both significant new development as well as a substantial level of development pre-dating the year 1900. This latter fact permitted the investigators to assume a continuing need for maintenance, renovation, and alteration.

4. Existing Land Management Controls

The land runoff controls generally applied in the study area must be identified. Although land runoff controls include regulatory, physical, and maintenance controls, at this juncture assessment of existing use can be limited to regulatory and maintenance controls. Applied physical controls are more difficult to catalogue and are generally included as requirements of regulatory controls. To a certain extent, maintenance controls are also included as such requirements. The zoning and subdivision regulatory documents of each municipality must be reviewed. The same applies to all building or construction codes as well as special environmental ordinances. The objective of these reviews is to ascertain to what extent these regulations provide controls on land development activities that minimize water quality degradation.

Most of these regulatory tools have been created to satisfy objectives other than water quality improvement. Some ordinances governing environmentally sensitive areas have at best made water quality upgrading an objective in addition to general objectives such as protection of persons and property. Regulatory tools having the strongest water quality objectives include up-to-date subdivision or land development regulations, steep slope or hillside protection regulations, flood plain or flood protection regulations, and erosion and sedimentation control regulations.

Examination of municipal codes may show these regulations to be in a common ordinance, such as a land development ordinance. Occasionally, some of these regulations are mandated by state or county law. In the case of the Lower Wissahickon, for example, the Commonwealth of Pennsylvania has adopted erosion and sedimentation control regulations and procedures that apply to all municipalities.

Upon identifying the relevant documents, two inventories should be compiled, one of controls common to all new land development and the second of controls applicable to all forms of maintenance, renovation, and alteration to existing development. The latter inventory will probably be more difficult to complete because many of the controls on building renovation or alteration are tied to building permit processes and their statutory basis in construction or building codes. These are regulatory tools which typically do not contain provisions for water quality objectives other than plumbing-related specifications. Some maintenance activities, e.g., street sweeping, and solid waste management functions such as trash removal and landfill operations, may be provided for under state mandates to local government and may not require local ordinances. The problem in these cases is lack of information, such as frequency of sweeping or trash collection and conveyance, which is essential to assess control effectiveness properly.

Finally, maintenance construction controls should include road and highway building, repaving, and widening. In each state, the responsibility for roads is divided among municipal, county, state, and federal governments. The controls on each level, if they exist at all, will differ significantly in terms of their water quality implications. In practice, many of the physical controls applied to new land development can be applied to road construction. This is particularly true for sedimentation basins, grade stabilization structures, mulches, nets, pervious blankets, and sandbag or straw bale barriers. An interview with local, county, and state highway or public works agencies would suffice to identify controls currently being applied. Visits to road maintenance or urban renewal sites are instructive and should be included in the design of the field study.

5. Assessing the Effectiveness of Land Management Controls

This methodology requires that the effectiveness (measured as sediment load reduction) of controls be determined for each land management control program of each subarea. This measure is referred to as the K2 factor, derived from the following equation:

$$K2 = 1 - (KNLD + KO + KA)$$

where:

1 = No reduction of load due to control practices

KNLD = Reduction factor for control practices applied to New Land Development

KO = Reduction factor for general land maintenance practices, not including that applied to new land development

KA = Reduction factor for control practices applied to agricultural (crop) production

The case study explains in detail how K2 factors for each land use category of each subarea are determined.

(A) Regulatory Control Effectiveness: Table 3 illustrates a point system for ranking regulatory controls according to their capability to achieve pollutant load reduction. Three points represented a control capable of significant load reduction, 2 points moderate, 1 point minimal, and 0 points no load reduction.

TABLE 3

REGULATORY CONTROLS: POLLUTANT LOAD REDUCTION FACTOR POINTS

Load Reduction Points	Description
Zoning	
1	General Zoning Ordinance Contents
2	PRD or Cluster Provisions
1	Mixed or Averaged Density Provisions
2	Flood Plain Designation
2	Steep Slope Designation
1	Agricultural District Designation
Subdivision Ordinance	
3	General Subdivision Ordinance
1	Surface Drainage Plan Requirement
1	Net Runoff Limitations
1	Structures: Runoff Reduction On-site
1	Structures: Sedimentation/Erosion Control On-site
1	Maintenance Requirements
1	Tree Protection/Preservation Requirements
1	Connection to Public Sewer Required
Steep Slope Protection Ordinance	
2	
Flood Plain Protection Ordinance	
2	General Ordinance
1	Runoff Control Criteria
1	Erosion Control Criteria
1	Streambank Alteration Criteria
1	Watercourse Alteration Criteria
2	Stream Setback Requirement
PRD or Cluster Ordinance	
2	
Average or Mixed Density Ordinance	
1	
Environmental or Community Impact Statement	
2	
Erosion and Sedimentation Control Regulations	
3	

Technical information on the effectiveness of such controls is not currently extensive, although a significant amount of current research addresses this subject. Whatever technical information is available to the 208 planning agency should be coupled with any available, locally-based data on the effectiveness of controls. Of particular value are the following technical documents:

> Urban Stormwater Management and Technology, An Assessment. A report by Metcalf & Eddy, Inc., Palo Alto, California, for the National Environmental Research Center, U.S. EPA, Cincinnati, Ohio, December 1974.
>
> Water Pollution Aspects of Street Surface Contaminants. A report by James D. Sartor and Gail B. Boyd for the Office of Research and Monitoring, U.S. EPA, Washington, D.C., November 1972.
>
> The Urban Stormwater Runoff Presentation. Printed text of presentation by Dennis N. Athayde and Andrew Waldo of U.S. EPA Water Planning Division, Washington, D.C., to EPA 208 Planning and Implementation Conference, Boston, Mass., March 1977. Available from EPA.

The data in these documents are applicable to maintenance construction controls as well as new development construction controls. They address primarily the relative effectiveness of physical controls. This information can be extrapolated to determine the effectiveness of municipal regulatory controls. In so doing, however, it is essential to include factors for implementation probability, in that such controls are not by themselves assurances of physical control implementation.

In order to derive the scores in Table 3, it was necessary to consider the objective of each control, its relationship to water quality management, and the types of physical controls required by each. Literature values were used to assess physical control effectiveness and comparisons were then made between the controls listed. As examples, erosion and sedimentation control regulations (which had a score of 3) have a direct relationship to water quality management and physical controls commonly required by such regulations achieve 50-90% sediment removal effectiveness according to sources just cited. At the other extreme, average or mixed density ordinances (score of 1) bear only a marginal relationship to water quality management and may require no specific physical controls. Its value is more important from the macro view of overall municipal development through the preservation of open space and minimization of land disruption.

(B) Maintenance Control Effectiveness: For maintenance control effectiveness, a similar point system was also used in the case study. Table 4 illustrates the types of controls and their associated point ranges. As indicated, the highest point score possible is 10, which represents a well developed, generally effective program of maintenance controls for developed areas. The categories of maintenance controls determined to be significant for the case study were:

- General land use policies
- Public cleanliness measures
- Controls on state and local road building
- Controls on maintenance

TABLE 4

RANGE OF LAND MANAGEMENT CONTROLS IN DEVELOPED AREAS

Maintenance Controls	Point Range
General Land Use Policy (includes zoning and building controls)	0 - 1
Public Cleanliness	0 - 4 (total)
Street cleaning (0-1)	
Catch basin cleaning (0-1)	
Refuse & litter collection (0-1)	
Sewer flushing (0-1)	
Controls on State and Local Road Building (includes street maintenance)	0 - 2
Controls on Maintenance Construction	0 - 3
Total Control	0 - 10

In applying this approach, the choice of numbers of points for each category should be predicated on:

- Whether the type of control is being applied in the study area
- The adequacy of the control in accomplishing its objectives

As an illustration of this point system, see pages 132-135 in the case study. As Table 25 illustrates, the urban areas in the Wissahickon Watershed received 6 out of 10 points. These six points were associated with a pollutant load reduction factor of .41, the derivation of which is explained in the case study. Using a linear scale of ten, this means that the maximum reduction capability of the control system described in Table 4 would be approximately 70% of the total load.

This approach and rating scheme seemed reasonable for this case study as well as other studies using this methodology, assuming the following assumptions:

(1) Land management regulatory programs for newly developed areas are inadequate in some localities.

(2) Inspection and enforcement of land management regulatory programs for newly developing areas are more stringently performed than in developed areas.

(3) The application of physical controls is more easily arranged on new sites than on developed sites undergoing change.

(4) The state-of-the-art of public cleanliness and maintenance construction control is at a developmental stage in which controls and practices are being discussed, tested, and evaluated. Neither a firm approach or consensus on the components of the approach are available at this time.

(C) Control Effectiveness by Subareas: This methodology requires that a K2 rate (sediment load reduction) be determined for the land runoff control program of each subarea.

The difficulty in doing this is that each subarea is comprised of partial or entire municipalities, each of which has a distinct and different control program due to any of the following factors:

- Date of municipal incorporation and subsequent maturity in land management regulation
- Amount of land annually undergoing new development
- Existence of environmentally sensitive areas in municipality and corresponding response to protection of such areas

At the subarea selection stage (see p. 18), it was suggested that the factor of control be considered and that, consequently, municipal boundaries be considered along with hydrologic boundaries as determinants of subarea boundaries. The control effectiveness of the subarea is actually the sum of the control effectiveness of each of its constituent municipalities. Although this is the conceptual approach recommended in this methodology, and was the approach applied to the case study, there is a subtle limitation: the land management controls on new development are a factor only if there is evidence of new development or potential for such development. It is important to examine the split of municipalities between subareas to determine if land in a subarea actually has land development potential. This would be an issue in a municipality with a sophisticated control program and an area most prone to receive development. If that municipality is divided into two or more subareas, the planner should be careful to assess whether a high reduction factor is appropriate in each subarea, or just the subarea containing land most prone to development.

If the land management controls for new development have been inventoried, then the point system for relative control effectiveness as presented in Table 3 and explained on p. 43 can be developed for each municipality in the watershed. This has been done in Table 22 in the case study. The product is a list of municipalities, each identified by its total control points.

The point system in the case study (see Table 22) showed that the highest point total for a municipality was 18, corresponding to a total load reduction of 95%. On a linear scale, the lowest point total of 6 corresponded to a 30% reduction. These reduction factors for each municipality applied only to new land development and are based upon:

- A literature review of the general effectiveness of each control for new land development
- An assessment of the existence and adequacy of controls used in the study area

For existing development, a similar approach should be employed using tables of potential controls, potential control effectiveness ranking, and controls currently employed by municipalities. In the case study, it was determined that controls on existing land development were not sufficiently practiced throughout the watershed but were generally practiced in certain types of urban and suburban areas. Consequently, reduction factors were generally derived for land use categories rather than for subareas. Each subarea had the identical set of existing land development reduction factors assigned to it.

The approach recommended in this methodology for determining new land development control effectiveness of each subarea is to execute the following equation and sequence of steps:

$$\mathrm{KNLD} = \sum_{i=1}^{n} X(i) \cdot \mathrm{knld}(i)$$

where:

KNLD = New land development control factor for subarea

n = Municipalities in subarea (1 through n)

X(i) = Per cent composition of subarea by municipality i

knld = New land development control factor for municipality i

1. Determine the percent composition of each subarea by its constituent municipalities. (i.e., 50% of subarea is Township X or part thereof, 30% is Township Y, and 20% is Township Z).
2. Multiply the percent composition of each municipal part of the subarea by its new land development control factor.
3. Add the product of each to arrive at the new land development control factor for each subarea.

I. MASS BALANCE ANALYSIS

The mass balance analysis compares the accumulated nonpoint source pollutant loadings at summation points calculated in two ways: (1) from measured water quality, and (2) from the application of pollutant loading factors to land uses in the study area. The nonpoint source loadings calculated from the application of loading factors to land uses are calibrated to the measured loadings. Differences between the measured loadings and calculated loadings are reconciled by re-examining raw loading factors and modifiers.

The measured nonpoint source loading is calculated from the data previously obtained in the section, "Water Quality and Pollution Load Analysis." Basically, the nonpoint source loading equals the total measured loading (on a per storm or annual basis) minus the point source loading (obtainable from NPDES permits).

The nonpoint source loading based on land use is calculated by applying the land use factors (modifiers) and raw loading rates previously derived in the section, "Land Use and Nonpoint Load Analysis." In-stream removal rate is also applied to account for the various removal processes that occur in the stream (e.g., biological uptake, oxidation, hydrolysis, sedimentation, etc.)

1. Application of Modified Soil Loss Equation

The modified universal soil loss equation applied in this methodology aggregates land uses into major categories and assigns raw loading rates (K) to these major categories. The modifying factors R, LS, P and SD are estimated based on overall determined land use, slopes, hydrologic condition, drainage density and general levels of observed controls.

Care must be exercised when aggregating land use/subareas. For instance, a 1976 EPA publication, Areawide Assessment Procedures Manual (Volume 1, pages 4-48) provides criteria and caution on the use and application of the universal soil loss equation. To use the equation correctly the combination of selected factors must reflect the manner in which the parameters are associated in each subarea.

Other simplifications in the modified soil loss equation include the following:

(A) The rainfall factor "R" is set equal to unity "1" for the calibration year. Other years simply assume a magnitude of R based on the ratio of their rainfall to that of the calibration year.

(B) The slope factor "S" and the length of slopes "L" are calibrated to a single "SL" factor.

(C) The soil erodibility factor "K" includes cropping factors for typical land uses and is expressed as the basic raw loading rate in lbs/acre/yr.

To facilitate application of the modified soil loss equation to typical 208 areas, the following additions were made:

(D) The erodibility factor "K" is also applied as a raw loading factor to typical urban areas to represent scour of sediment loads from impervious surfaces. These are based on measurements of sediment loads from typical urbanized areas.

(E) The erosion control practice factor (P) was divided into two separate factors: natural controls (P) and man-made controls (K2). This disaggregation allows the user more freedom to determine the effectiveness of man-made controls.

2. Calculation of Nonpoint Source Loading

The raw runoff factor (K) developed previously and the runoff modifers R, LS, SD, P and K2 are assigned to their respective land uses within the subareas defined.

The resulting loadings from land uses for each subarea are summed to provide the overall total annual nonpoint source loading at each of the summation points as shown in the flow diagram of Figure 4.

$$Y_{(S)E} = \sum_{i=1}^{n} A(i) \cdot K1(i) \cdot K2(i) \cdot KN(i)$$

where:

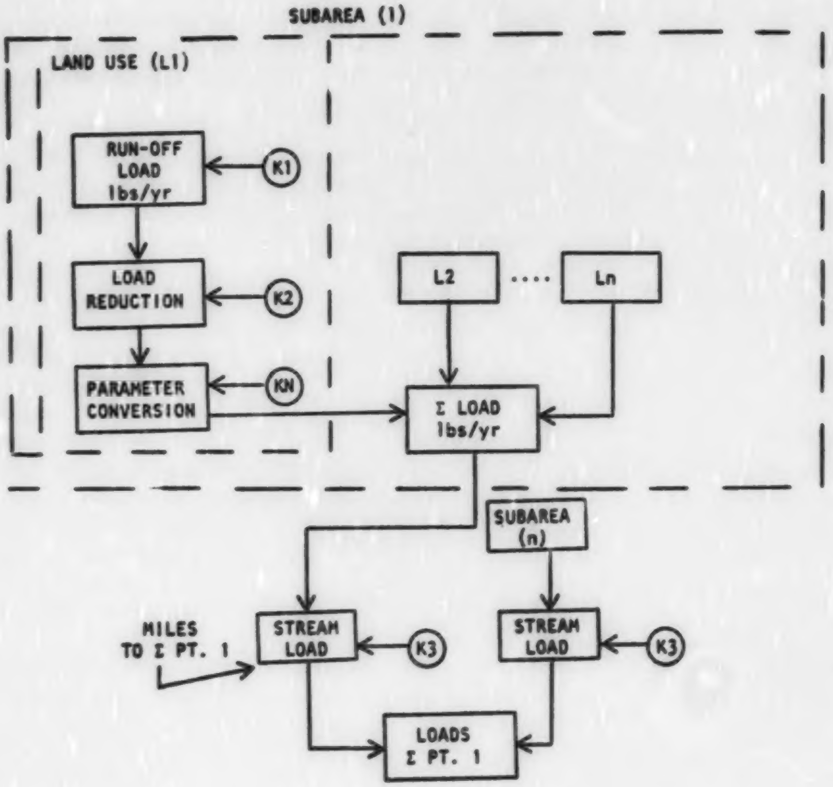
$Y_{(S)E}$ = sediment loading in #/yr for subarea
n = land use category (1 through n) (see p. 22 for derivation of categories)
A(i) = area of land use within subarea in acres
K1(i) = (lbs/acre/yr) is the product of the following terms: R, K, LS, SD and P.

R = (Dimensionless Ratio) factor expressing ratio of annual rainfall intensity to that for the year of calibration.

K = (lbs/acre/year) raw sediment runoff rate for each land use category. Using measured runoff from typical land use areas and literature values as modified by intensity of land use and construction activity.

LS = (Dimensionless Ratio) expressing the effect of slope steepness and length.

SD = (Dimensionless Ratio) expressing function of sediment reaching streams. Factors consider proximity to receiving streams and soil runoff potential. Runoff potential of impervious surfaces is assumed very high.


SUBAREA (1)
LAND USE (L1)
RUN-OFF LOAD lbs/yr
K1
LOAD REDUCTION
K2
PARAMETER CONVERSION
KN
L2
....
Ln
Σ LOAD lbs/yr
SUBAREA (n)
MILES TO Σ PT. 1
STREAM LOAD
K3
STREAM LOAD
K3
LOADS Σ PT. 1

K-FACTORS

K1 - Sediment Run-off Rate (lbs/acre/yr)

K2 - Land Management Controls (% reduction)

KN - Ratio Load (N) to Sediment (Dimensionless)

K3 - Stream Reduction Rate (% Reduction/Mile)

Source: Betz Environmental Engineers, Inc.

FIGURE 4

EPA LAND USE LOAD
DETERMINATION FLOW DIAGRAM

P = (Dimensionless Ratio) reduction factor expressing percentage of sediment reaching stream as a result of natural existing sediment or erosion control factors. Best management practices are encompassed in the term K2.

K2(i) = (Dimensionless Ratio) reduction of stream load resulting from existing and planned future implementation of land management controls.

KN(i) = (Dimensionless Ratio) ratio of concentration of parameter (N) such as nitrogen, phosphorus, or metal to that of sediment for each land use. This term is set equal to 1.0 for sediment runs.

The summed annual nonpoint source loadings from each subarea reaching the stream are reduced by the factor K3, which represents the rate of reduction of pollutants within the stream due to settling, biological consumption, etc. All of the loadings from each subarea are summed to present an annual pollutant load at each of the three summation points.

A typical mass balance computer program output is shown in Appendix B. The first two pages show the land use areas and the loading factors employed for each subarea and land use, and the third page shows the summation of resulting loads for each subarea and summation point. This same format is used to present outputs for each pollutant run and each control option run, thus simplifying a comparison between loadings and loading factors. The methodology for using and applying the computer mass balance program for a nonpoint study is explained below. A typical case study, the Lower Wissahickon Watershed, is presented in Section IV.

3. Calibration of Sediment Loads

Using the loading factors previously developed for the calibration year, a mass balance of sediment loading is performed by using the simplified mass balance computer program or desk top calculations. The resultant calculated loadings at summation points are then compared to the measured loadings at these same points. Differences are resolved and the land use factors are adjusted to provide a calculated loading that matches the measured loading. These adjustments are not arbitrarily made to provide a calibration fit. Rather, the factors and loadings of each subarea are re-examined with the aim of uncovering discrepancies in any of the loading factors. In no case should unrealistic loading factors be employed merely to obtain a fit. When the calculated and measured loadings at the summation points are in reasonable agreement (within 10%), all factors should be increased or decreased proportionately to provide an exact match of the calculated-to-measured-year loading. This mass balance then constitutes the "best-fit" calibration of sediment loads. See the case study (page 137) for a further explanation of the application of calibration procedures.

4. Verification of Sediment Loads

Verification is based on matching calibration results to verification sediment loading data for a year separate from the calibration year or from data from a separate storm event within the calibration year. Careful consideration of the margin of safety that surrounds and limits unqualified verification should be taken into consideration. Although decisions must be made in the near term an appreciation for and an effort to improve the margin of safety for the data should continually undergo review and reevaluation.

(A) Separate Year Verification:

Using the loading factors from the best-fit calibration of sediment loads and a rainfall factor "R" corresponding to the rainfall of the verification year, a mass balance is run. Appropriate adjustments to compensate for differences in land use between the two years may be required.

The calculated loading at the summation point is compared to the verification loading measurements. The degree of fit to be expected of calculated versus measured loadings depends on the quality of the measured verification data and the confidence the user has in the calibration land use factors. With reasonable confidence in verification data and land use factors, a degree of fit within 20% can be expected. If the fit is outside this range, both the calibration "best-fit" and the verification data are suspect. Both should be reexamined to determine the cause of the misfit. Calibration "best-fit" may require a re-adjustment in the loading factors. Both calibration and verification results must be satisfied with the same loading factors employed, with the exception of the rainfall factor "R" which is, of course, tailored to each condition. No unreasonable factor should be employed to obtain best fit.

(B) Separate Storm Verification: The procedure for verifying separate storms is the same as it is for separate calibration and verification years, with the exception that the rainfall factor represents the ratio of the single verification storm rainfall to the total rainfall of the calibration year. The degree of fit between calibration and verification of a single storm rainfall could be somewhat looser than that derived for separate verification years in that errors of data for individual storms are averaged out for a total composite year.

5. Calibration and Verification of Other Pollutant Loads

Using the calibrated and verified sediment loadings model, other pollutant parameter loadings can be computed as a function of the sediment loading by using the KN ratios (ratio of measured pollutant load to measured sediment load) previously developed for each land use. The computed loading of each pollutant is compared to the measured loading, and discrepancies are resolved. Adjustments can be made in the KN ratios, but it is inadvisable to make changes in the basic sediment calibration model loading factors. Potential errors in the KN ratio are listed below:

- Errors in determining the KN ratio (calculations and supporting data)
- Existence of significant soluble pollutants (see previous discussion of KN rates)
- Failure to recognize the propensity of pollutant to be transported by finite size range of sediment particles

It is advisable to concentrate adjustments on the first two potential errors. It is beyond the scope of the technology presented in this report to include the complex analysis of the latter potential error sources. The basic sediment mass balance model does not have the capability to include this factor, and adjustment of KN ratios based on this factor should not be attempted unless a sufficient data base exists.

J. WATER QUALITY IMPACT ANALYSIS

The primary purposes of this analysis are to (1) verify and modify the preliminary identification of the water quality problems, and (2) formulate allowable pollutant loadings to meet applicable water quality standards. These waste load allocations should be divided into point and nonpoint source. Based on these allocations, nonpoint source control options should be evaluated to determine (1) what controls will effectively reduce pollutant loadings to the allocated amounts, or (2) whether nonpoint source control measures will be able to produce the required pollutant reductions. If nonpoint source controls are insufficient to produce the required pollutant reductions, the maximum estimated pollutant reductions should be applied to the study area, and the water quality analysis (mass balance, model, etc.) should be rerun to project the resulting water quality based on application of the nonpoint source controls.

In many instances a reiterative process will have to be applied. For example, a given set of controls should be selected. The resulting pollutant loadings based on these controls should be input to the water quality analysis to project future water quality. If the projected water quality does not meet standards, additional controls should be applied, and the water quality analysis should be rerun to determine revised water quality projections. This reiterative process should be performed until (1) the projected water quality meets the standards, or (2) some intermediate water quality level is projected from the application of the best available nonpoint source controls.

The impact of nonpoint loadings on water quality and biota are determined in three steps:

Impact on chemical water quality
Impact on stream bed and substrates
Impact on biology of receiving waters

1. Impact on Chemical Water Quality

Nonpoint load impacts on chemical water quality must be viewed in terms of short-term and long-term effects. In the short-term during and immediately following storms, significant increases occur in total pollutants present; however, these are coupled with corresponding increases of dilution waters; therefore, short-term concentrations of pollutants may not cause short-term water quality problems. The typical behavior of the streams under consideration are best determined by examining hydrographs and pollutographs constructed as a result of storm monitoring at the summation points.

Because the modeling technique allows a separation of point source loads from nonpoint source loads, these hydrographs and pollutographs can be modified to show the increase or decrease in concentrations that would occur for future land use projections and controls. These hydrographs and pollutographs will be at best approximations because new development would alter peaks, delays and general shape of the hydrograph and pollutograph as well as the total overall loads. Nevertheless, they should be valid to illustrate relative significance of impacts of different land uses and alternatives.

The long-term impacts of water quality can be ascertained by determining the average concentrations of pollutant loads based on total annual loads (both point and nonpoint) and total annual flow (see Lower Wissahickon Watershed Case Study for typical analysis). Accompanying field studies can reveal specific nonpoint problem areas where the nonpoint sediment and pollutant loads accumulate and cause benthic problems and exercise a BOD demand and resulting low dissolved oxygen during low flow, steady-state conditions.

Another potentially significant long-term effect of nonpoint pollutants is in downstream receiving waters where eutrophication may occur. In these cases, the algal growth and limiting factors must be determined and mass balance techniques must be employed to determine the effects of the nonpoint source loads (see Impacts on Biota.)

2. Impact on Stream Bed and Substrata

The impact on stream bed and substrata is mainly determined through field surveys. This impact results from separate but interdependent effects: (1) scouring of stream banks caused by increased flow, and (2) deposits of sediment and other pollutants in dormant pools or basins within the stream. Both of these are aggravated by increased development and impervious cover which causes higher peak flows and pollutant loads. The effects of stream bed problems on steady-state water quality characteristics and the destruction of natural habitat for biota should be studied by field surveys, preferably following storms (see the results of field studies conducted during the case study).

3. Impact on Biota

The chemical water quality data and stream bed alterations provide the basis for assessing the potential for adverse biological conditions caused by nonpoint source pollution. It is then necessary to provide biological data to determine whether biological degradation is occurring. The chemical concentration data used in conjunction with water quality criteria standards for aquatic organisms and scientific papers reporting tolerances of aquatic organisms will indicate the potential for adverse environmental impacts. In the case of suspended solids, the degree and location of settling is also important in determining the affected area.

The next step is to examine the biological data to determine whether degradation is indicated. Macroinvertebrate and algae data are most important for this evaluation. Fish, because of their mobility, have the capacity to move in and out of affected areas and may not reflect the presence of intermittent adverse conditions.

If the biological data indicate a community structure and composition that reflect the chemical data and sedimentation projections, it can be concluded that nonpoint source pollution is causing biological degradation. However, other factors that could influence the biota must be considered. All point source effects must be evaluated, natural habitat influence must be considered, and the season, recent weather conditions and methodologies used for the biological data collection must be studied.

The best way to eliminate these factors is to compare data from areas comparable in habitat availability, physical conditions, and data collection techniques, but with potential nonpoint source pollution affecting only one area. If the areas are comparable, major differences between them are probably a result of nonpoint source pollution.

In addition, downstream waters should be analyzed to determine if eutrophication, or the potential for it, is present. If eutrophication problems exist as evidenced by algal blooms, in-depth water sampling and algal identification should be conducted. Factors and pollutants which provide limiting ingredients for algal growth should be ascertained. Finally, mass balances of nutrient enrichment should be conducted using the point and nonpoint loads resulting from the model. By using model runs for projected land use and controls, the general impact of development and controls on eutrophication can be assessed.

4. Summary of Nonpoint Loadings on Water Quality

The observed impacts of nonpoint loadings on chemical water quality, stream bed and biota are summarized and analyzed to assess a cause-effect relationship. A discrimination is made between those problems caused by point source discharges and nonpoint pollutant runoff and wasteload allocations are made for point sources and nonpoint sources of pollutants.

The point source impacts are most readily identified by using steady-state modeling. In many 208 areas, steady-state models may already exist. These models include the effects of point sources during low stream flow conditions when the effects of point sources are most prevalent because of the absence of dilution waters. The steady-state models also can offer some insight into nonpoint source pollution effects by identifying existing benthic deposits, which may be a result of settled sediments from previous storms. These benthic deposits exert an oxygen demand during later low flow periods. Areas of large benthic demand are readily determined by examining steady-state model results. Steady-state models will also reveal portions of the stream in which eutrophication or high algal blooms occur. These, too, can be the result of nutrients washed off of the land during previous storms.

If there are no steady-state models and budget or time constraints prohibit the development of such models, a less comprehensive mass balance approach can be used wherein a balance of point source pollutant inputs (determined from NPDES permits) are compared to the load measured at the summation points during low flow conditions. Care must be exercised to include the effects of the loss of point source pollutants in the stream through consumption or settling. A description of steady-state modeling techniques and mass balance techniques and their capabilities and shortcomings are presented in the EPA publication "Simplified Mathematical Modeling of Water Quality," March 1971. Point source control options can then be explored to assess the degree of improvement possible or practical under point source control management.

Once the total effects of point source pollutants are ascertained, the remainder of the water quality problems can be attributed to nonpoint sources. Wasteload allocations of nonpoint sources can then be assessed. Some water quality problems can easily be ascribed to the effects of nonpoint sources, such as scouring of stream beds and sediment deposits. Other problems, such as nutrient build-up and areas of large benthic demand, are more difficult to assess because they could originate from point sources, nonpoint sources or a combination of both. Benthic deposits of oxygen demanding water originating from point sources usually occur a short distance downstream from the point source discharges. An examination of the hydraulics, point source locations and benthic deposit locations can reveal a cause-effect relationship.

It is extremely difficult to determine the exact magnitude of the reduction of nonpoint source loads that would meet receiving water quality standards. The complexity of the many stream flow regimes encountered in low flow and storm flows of varying intensity result in pollutant dispersion that is often too difficult to assess. For example, a storm of one intensity might wash off land pollutants to be settled in a given stream bed location, while a storm of a more increased intensity would result in scouring that deposit and washing it into receiving waters further downstream. The answers to such questions are usually beyond the capability of even the most sophisticated storm modeling techniques. Therefore, the methodology presented herein is limited to identifying the existence of nonpoint source problems, their relative order of magnitude and their isolation to given pollutants and probable sources. The mass-balance modeling approach provides a tool that enables the user to attribute problems to specific land use sources and, through the use of the sensitivity analysis, determine the most cost-effective nonpoint management alternatives which would reduce the nonpoint loads to within acceptable limits of the overall assimilative capacity of the receiving waters.

K. SENSITIVITY ANALYSIS

The sensitivity analysis provides the framework for determining the land management control techniques to be applied. Data from the sensitivity analysis are helpful in providing answers to such questions as:

- Which land areas are least sensitive to development?
- Which land uses and subareas contribute the most significant nonpoint loads?
- Which land management controls are most promising?

To gain these sensitivity criteria, several mass balance variations of the sediment calibration condition must be run. Separate mass balance rates are made incorporating the following changes:

(A) The slope lengths (SL) are assumed to be at the minimum value (i.e., all slopes theoretically less than 2%).

(B) The sediment delivery ratios (SD) are assumed to be 1.0 for each land use and subarea (i.e., all eroded sediment is delivered to the stream).

(C) Natural erosion control factors (P) are set to 1.0 (i.e., all natural sediment control factors are eliminated).

The man-made control factors (K2) are set to their best practical value (i.e., all existing controls are upgraded to their best practical implementation). These may be considered separately for each land use or run in combination with controls for land use groupings. See Lower Wissahickon Watershed Case Study for examples.

The loadings from these computer runs are then extracted and summarized to form sensitivity analysis criteria as shown in Table 5, which summarizes loads at each mass balance point. Loads are shown as a function of each of the loading factors and in terms of total load change in lbs/yr, loading rate change in lbs/acre/yr and the percentage of load change for each loading factor. The criteria presented in this table can be used to determine overall basin problem areas.

Similar tables expressing sensitivity criteria for subareas and land use levels can be derived to identify land uses and subareas which are significant contributors to pollutant loadings. These criteria can then be related to pollutants and land uses which contribute heavily to identified water quality problems. Together, these criteria provide the basis for determining:

- Basin-wide problem areas
- Isolation of problems to subareas
- Isolation of problem land uses within each subarea
- Which areas, if developed, will provide the least nonpoint impacts
- Where development on steep slopes would be less conducive to nonpoint problems
- Where sediment basins might most effectively be used to reduce sediment delivery
- Where and which controls will be most cost effective in reducing pollution loads for existing and projected futures

TABLE 5

LOADING FACTOR SENSITIVITY - MASS BALANCE POINTS

Parameter	Description(1)	Load Change(2) Σ PT 1 lbs/yr	 Σ PT 2 lbs/acre/yr	 Σ PT (n) percent
LS	Load changes as a function of slope-lengths	x lbs/yr(1) x lbs/acre/yr(2) x % (3)	X	X
SD	Load changes as a function of sediment delivery ratio	X	X	X
P	Load reductions as a function of natural control factors	X	X	X
K2	Load reductions as a function of existing Best Management Practices	X	X	X
K2(3)	Maximum load reduction possible under practical limits of Best Management Controls	X	X	X

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(1) See pages 148-150 of the case study for an explanation of how to obtain values.

(2) Effect of parameter on total load at summation point.

(3) Effect of using best available BMPs throughout study area.

L. CONTROL PLAN DEVELOPMENT

The value of the model and methodology in the development of construction and other nonpoint source control plans should be apparent after examining its output. The output information includes summation point loads, total in-stream loads associated with land use categories of each subarea, and the sensitivity of these loads to any variable changes in the USLE-modified equation. Of primary interest is the sensitivity of the model to changes in the load reduction factor, which takes into account controls placed on new land development, existing development, and agricultural activity.

The model can be used to assess the effectiveness of the existing control mechanisms on in-stream pollutant loads. It can also be used to evaluate which land use categories are the major contributors of such loads under controlled and uncontrolled conditions. The data can be produced as total load associated with each land use for the study area or for each subarea. It can also identify the nonpoint source load per unit of land (e.g., lbs/acre/yr) such that the relative pollutant load generation of one land use can be compared to another.

If information on the effectiveness of physical controls is available, it is possible to test a "promising control system" in the model to ascertain its in-stream effects. The marginal benefits in effectiveness between promising alternative systems can then be compared with the direct and marginal costs associated with each system.

Although this methodology is based conceptually on a relatively simple equation, sensitivity of the model to the quality of data always leads to questions of accuracy and degree of error. Of particular importance are data on loading factors and effectiveness of controls. If such data are inaccurate, the identification of major contributing land uses, and further, the development of control systems for these land uses, may be inappropriate. As a tool for policy analysis and program development, caution is necessary in judging the accuracy and appropriateness of the methodology. It should be stressed that even the best analyses will only yield useful approximations which may allow better management of solutions in the near term. More precise tools will evolve if continued technical emphasis is given to calculating land use water quality relationships. High quality data will often need to be collected over a protracted period to permit a high degree of confidence with the data base.

Literature on new land development controls and their effectiveness is expanding. Nevertheless, where possible, data from available literature should be supplemented by actually testing the effectiveness of controls as applied in the study area. This also applies to controls associated with agricultural production and maintenance construction.

1. Use of Physical Controls

The range of alternatives for control plan development is broad. A myriad of plan alternatives can be created for controlling pollutants generated by new land development, existing development, or agricultural production. The control plan should provide a blend of physical controls to achieve the following objectives:

- Protect existing ground cover
- Control runoff velocity
- Filter runoff
- Contain sediment and runoff

As an aide to understanding how alternative plans (using different physical controls) may accomplish similar objectives, refer to Table 2. This table indicates the objectives accomplished by a representative list of physical controls. A choice can usually be made of the control to accomplish one of the objectives. Of course, the effectiveness of each control varies and the selection of plan components should be based in each case upon the requirements of the site, degree of sediment (or other pollutant) removal required, and marginal benefits and costs of alternative plans.

2. Use of Regulatory Controls

The use of on-site physical controls is usually required by a regulatory control such as, in the case of new land development, a subdivision ordinance or erosion and sedimentation control ordinance. However, there is a problem in specifying physical control usage in ordinances and other regulations. To achieve a high degree of effectiveness in pollutant load reduction, physical controls should be chosen and designed for the actual site under consideration. While certain standard physical controls are commonly used, each must be tailored to suit the topographic and hydrologic features of the site. In an effort to provide the flexibility required in choosing physical controls, a trend has developed in which subdivision and other environmentally sensitive ordinances have required the application of "performance standards." These standards translate objectives of the ordinance into quantitative goals.

An example of a performance standard would be no net increase in runoff from newly developing sites, or a minimum tonnage of sediment loss per unit of time during construction. The performance standard approach leaves the choice of physical controls and their implementation to the developer, who is responsible for meeting the performance standard.

3. Implementation of Regulatory Controls

In order for regulatory controls (and the physical controls which they may require) to be considered effective in reducing loads, they must first be implemented and enforced. For this reason, implementation is a key variable to be considered in this methodology. Proper implementation of regulatory controls by municipal governments implies that the controls are consistently applied when necessary with a minimum of waivers and variances and that developers implement the required physical controls. When using this methodology, the planner must take into account the probability of implementation in determining the effectiveness of regulatory controls. As an example of such a consideration, a sedimentation and erosion control ordinance, specifying physical controls determined to achieve 95% reduction of sediment loss, is less effective as a regulatory control if implemented by the municipality in only 75% of necessary cases. In fact, this regulatory control, under these conditions, might be 71% effective (.95 x .75 = .71).

As a guide, regulatory controls on the municipal level are more apt to be implemented if they contain provisions such as the following:

- Performance standards based on water quality goals

- Water quality monitoring requirements
- Requirements for site inspection by knowledgeable officials
- Procedures for enforcing the regulations, including imposition of sanctions

In addition to such ordinance provisions, implementation is generally encouraged where technical and program assistance is offered by appropriate government agencies such as planning commissions, soil conservation districts, health departments, and special municipal review boards such as environmental and architectural review commissions. Where such assistance is received by local regulatory authorities, the technical capabilities of municipal managers and their ability to understand control increases, leading to a better understanding of environmental problems, appropriate solutions, and consistency of implementation.

In determining the effectiveness of regulatory controls in the study area, thought should be given to the qualifications noted above. While these qualifications do not lend themselves to quantification, the use of good judgment should be sufficient to assess their impact on control implementation.

4. Regulatory Controls and Best Management Practices (BMP)

For construction, agriculture, and other pollutant-generating activities addressed by this methodology, the 208 planning agency should prescribe best management practices to be applied for the study area, county, or watershed affected. In some municipalities, the recommended BMPs will already be in effect. In many cases, BMPs already exist in many municipal regulatory controls. This is particularly true in the case of regulating construction activity, where many well designed subdivision and land development ordinances have required physical control techniques fitting the definition of BMP.

As a means of implementing BMP, 208 planning and management agencies should encourage municipal, county, and state governments to include their BMP recommendations as amendments or changes to existing regulations. Since BMPs are most effective when consistently applied throughout the study area, these efforts should be directed at all municipalities or through county government if statutory authority permits such regulation at that level of government. This issue is particularly important in study areas composed of large numbers of municipalities where inter-municipal cooperation is often difficult to achieve.

Two types of regulatory controls appear well suited as BMP mechanisms. The first are municipal ordinances which can be adapted to include BMP as requirements. If included in any of the types of ordinances listed on page 42, the municipality retains strong control through ordinance enforcement. State legislation permitting municipalities to pass local ordinances should be reviewed to determine limitations or qualifications in this area.

The second type of regulatory control suited for BMP are the state permit issuance programs. On the state level, permits are often required for wastewater discharge facilities, water supply, sewer extension, on-lot disposal systems, watercourse encroachments, erosion and sedimentation control, mining activities, and various other activities. Most state agencies which issue permits have the authority to attach conditions to permits which could include BMP for activities requiring them. In such cases, guidelines for permit issuance, generally published by such agencies as instructions to permit applicants, could specify types of BMP to be required as permit conditions. The enforcement of BMP, as elements of permit programs, is the role of the state government, or other state designated levels of government.

IV

CASE STUDY: APPLICATION OF METHODOLOGY

A. INTRODUCTION

The methodology presented in Section III was applied to a watershed in Pennsylvania to present a case study of the methodology. The purpose of this case study is twofold:

- To illustrate the applicability of the methodology for the analysis of land use-water quality relationships
- To demonstrate how the methodology can be applied to a specific watershed

To accomplish this it was necessary to select a small urbanizing watershed having a wide range of water quality and nonpoint source problems. The Wissahickon Watershed in Pennsylvania was selected because it fit the selection criteria of (1) an urbanizing area, (2) single and multi-family residential area, and (3) considerable new development. Its salient characteristics are:

- It covers a broad spectrum of land use. Its headwaters lie in rural areas that exhibit a mixture of agricultural use and suburban growth.
- Its mid-section is suburban, with a significant mixture of heavy and light industry, a high growth rate and accompanying new construction and road building.
- Its lower section lies within the city limits of Philadelphia in a region of high population density and old established neighborhoods where little new land development occurs, but where a large share of the city's urban renewal and redevelopment takes place. This section does have one distinguishing feature that may not be typical of most city environments: the stream threads

through Fairmount Park, where a relatively wide adjoining area of natural woodlands serves to retard nonpoint pollutant runoff. The buffering zone occurs to a much lesser extent in the mid and upper watershed.

- The watershed drains an area of 64 square miles and has a main branch 22 miles in length. Prominent features include its urban-suburban interface and high rate of development from the mid-section of the watershed to its head waters. The Wissahickon watershed is presented in Figure 5.

B. INVENTORY AND EVALUATION OF EXISTING DATA

A description of the case study data sources and their functional uses are presented in Table 6. These data were evaluated to determine land use characteristics and all of the land use loading factors required to apply the mass balance model to the Wissahickon Watershed. Calibration and verification data sets were also derived from these data, along with assessment of water quality problems. Deficiencies in these data were augmented by field surveys and a literature search of parameters and criteria from studies conducted in similar urbanizing areas. The applicability and use of these data are explained in detail in the subsequent paragraphs.

1. Water Quality Problem Analysis

Review of existing water quality and related data indicates that one of the primary water quality problems in the study area is steady-state nutrients. Although the high phosphorus levels in the Wissahickon Creek produce some localized or transient aquatic plant problems, the primary problem is produced in the Schuylkill River downstream of the Wissahickon Creek.* High phosphorus loadings from the Wissahickon Creek and the Schuylkill River combine to form eutrophic

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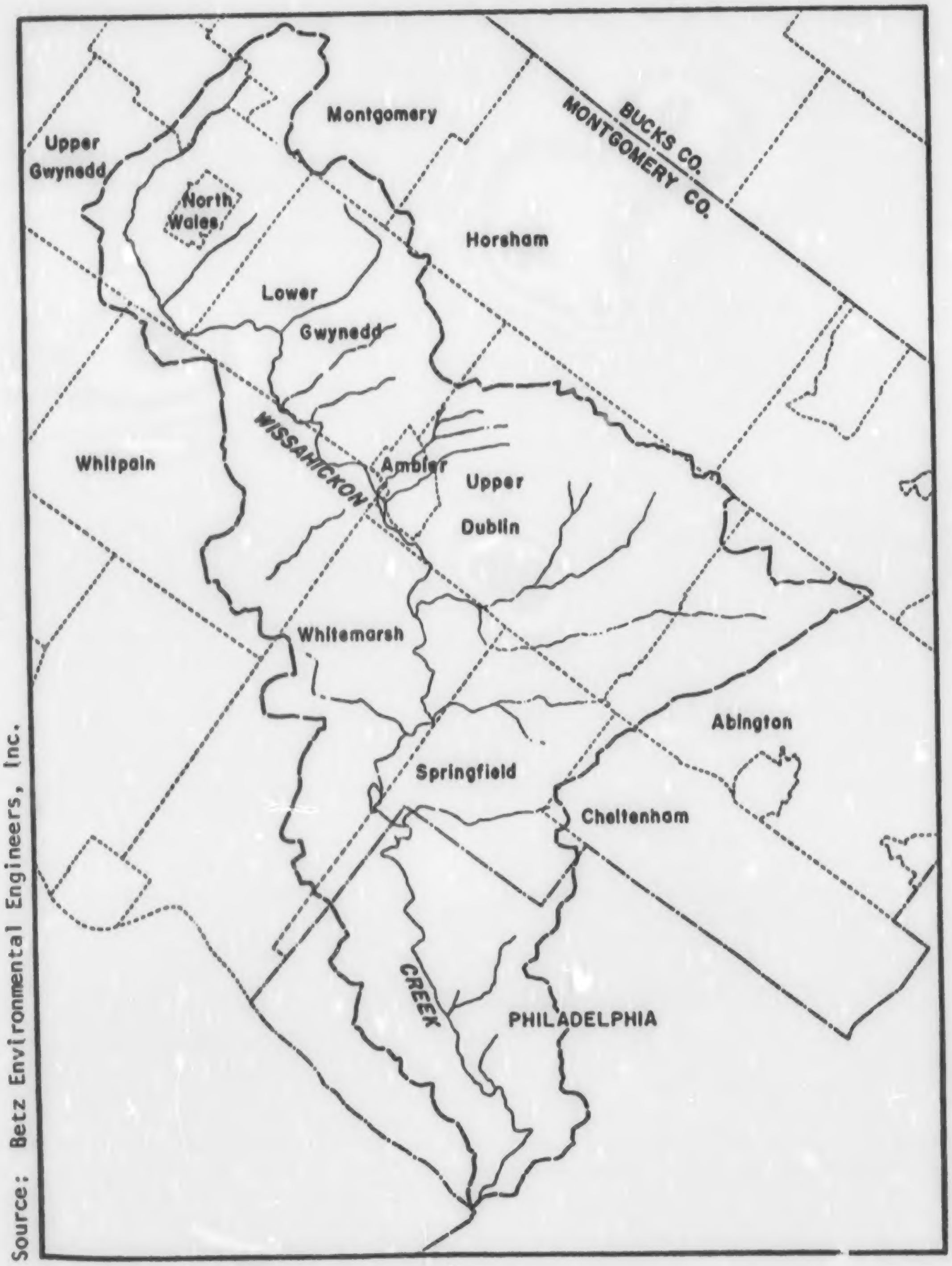
* The Wissahickon Creek is tributary to the Schuylkill River, which is used as a water supply for the City of Philadelphia.



Montgomery
Upper
Gwynedd
North
Wales
Horsham
BUCKS CO.
MONTGOMERY CO.
Lower
Gwynedd
WISSAHICKON
Ambler
Upper
Dublin
Whitpain
Whitemarsh
Abington
Springfield
Cheltenham
CREEK
PHILADELPHIA

Source: Betz Environmental Engineers, Inc.

FIGURE 5

MAP OF STUDY AREA

TABLE 6

WISSAHICKON WATERSHED CASE STUDY DATA SOURCES, DESCRIPTION AND FUNCTION

Data Source	Description	Functional Use
Philadelphia Water Department 1970-1974	Water quality data; monthly grab samples; 15 water quality parameters, Bells Mills station and mouth of Wissahickon Creek	Establish steady-state water quality conditions
Wissahickon Water Quality Model C. Gabriel 1974	Steady-state Water Quality Model: Dissolved Oxygen, BOD and listing of point sources and their effluent characteristics, 10 parameters	1. Establish steady-state water quality conditions 2. Determine point source total load and effects
United States Geological Survey Water Resources Data for Pennsylvania: Part 2. Water Quality Records 1964 and 1968(1)	Sediment load during storms at Fort Washington Station, Wissahickon Creek	1. Establish sediment calibration data set (1968) 2. Establish sediment verification data set (1964)
United States Geological Survey Water Resources Data for Pennsylvania: Part 1. Surface Water Records 1964 and 1968(1)	Daily flow records: Wissahicken Creek-Fort Washington, Bells Mills and Mouth	1. Correlate flow to sediment load 2. Extrapolate storm flow sediment load to total annual sediment load 3. Establish rainfall factor (R) baseline for calibration (1968) 4. Establish "R" factor for verification (1964)
NOAA, U.S. Department of Commerce Precipitation Records-Pennsylvania Annual Summary: 1963, 1964, 1967, 1968	Rainfall Records, North Philadelphia Airport (1967, 1968) and Phoenixville, Pa. (1963, 1964)	1. Correlate rainfall to sediment load 2. Develop "R" factor base for 1968 calibration 3. Develop "R" factor for verification (196
Northern Virginia Planning District Commission Quarterly Report Occoquan/Four Mile Nonpoint Source Correlation Study, October 1976	Storm loads for various land uses and rainfall: sediment, BOD, phosphorus, ammonia, TKN, nitrogen	Develop "KN" ratio for various pollutants
Wissahickon Watershed Wastewater Management Study, Betz Environmental Engineers, 1976	Biological survey of Wissahickon Creek, 6 stations (1972)	Determine existing biological conditions
COWAMP/208 Critical Slopes Map, Water Quality Management Plan Study (Chapter IV)	Map of slopes in excess of 12% grade	Develop slope length (SL) factor
USDA Montgomery County Soil Survey (1967)	Hydrologic groupings of soils, composition of soils	1. Develop sediment delivery ratio (SD) 2. Develop cropland sediment load rates
USDA Philadelphia County Soil Survey (1975)	Hydrologic grouping of soils	1. Develop sediment delivery ratio (SD) 2. Develop cropland sediment load rates
COWAMP/208 Storm Drainage Facilities Map	Storm sewer service areas, location and description of facilities	Identification of storm sewer drainage area and outlets
Montgomery County Planning Commission: Montgomery County Land Use Map	Land use categories	To broadly outline major land uses
Wissahickon Watershed Development Guide	Land use and development control guidelines for Philadelphia portion of Wissahickon Watershed	To broadly outline major land uses
Delaware Valley Regional Planning Commission Year 2000 population forecasts	Year 2000 population forecasts by municipality	To determine population and land use changes to year 2000
Municipal zoning, subdivision, and other ordinances	Local regulatory controls addressing the management of land	To determine the relative effectiveness of local regulatory controls
U.S. Geological Survey Topographic Maps, 1965, 1973 revisions	Maps showing topography, existing and new development, and natural features	1. To develop hydrologic divisions of subbasins 2. To identify areas of new land development 3. Develop slope length factors (SL) 4. Determine drainage density 5. Develop sediment delivery ratios (SD)
Aerial photography, 1973-75 photographs	Aerial photographs of land use and topography	To identify land use and development

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(1) Corresponds to USGS water year beginning November of preceding year and ending in September of year listed.

Source: Betz Environmental Engineers, Inc.

conditions in the downstream regions of the Schuylkill River. Excessive algal growths in this reach of the river cause treatment and taste and odor problems in the City of Philadelphia's water treatment plants. Nutrient-induced eutrophication problems occur on a regional basis during dry, low flow warm weather conditions.

A second and equally troublesome condition is sedimentation. Sedimentation from extensive development and construction within the watershed has destroyed much of the stream bed and biota.* In addition, the increased storm flows caused by increased impervious cover in the watershed has scoured the stream banks and uprooted trees. The stream surveys subsequently support these observations.

C. FIELD SURVEYS AND NONPOINT SOURCE MONITORING

1. Field Surveys

Two field surveys were performed during the case study. The first was a cursory survey to provide an overview of land uses, stream conditions and existing runoff controls prior to establishing loading factors for subareas and land uses. The second survey was performed after a heavy storm to determine the effect of nonpoint loads on water quality and biological conditions in the stream. Photographs of visible problem areas taken during these surveys were helpful in documenting problems and would be valuable for use in later public meetings to demonstrate these areas.

2. First Survey

The first survey was performed on January 31, 1977. Figure 6 presents a map of the survey sites. A summary of the findings appears in Table 7. This survey was conducted to

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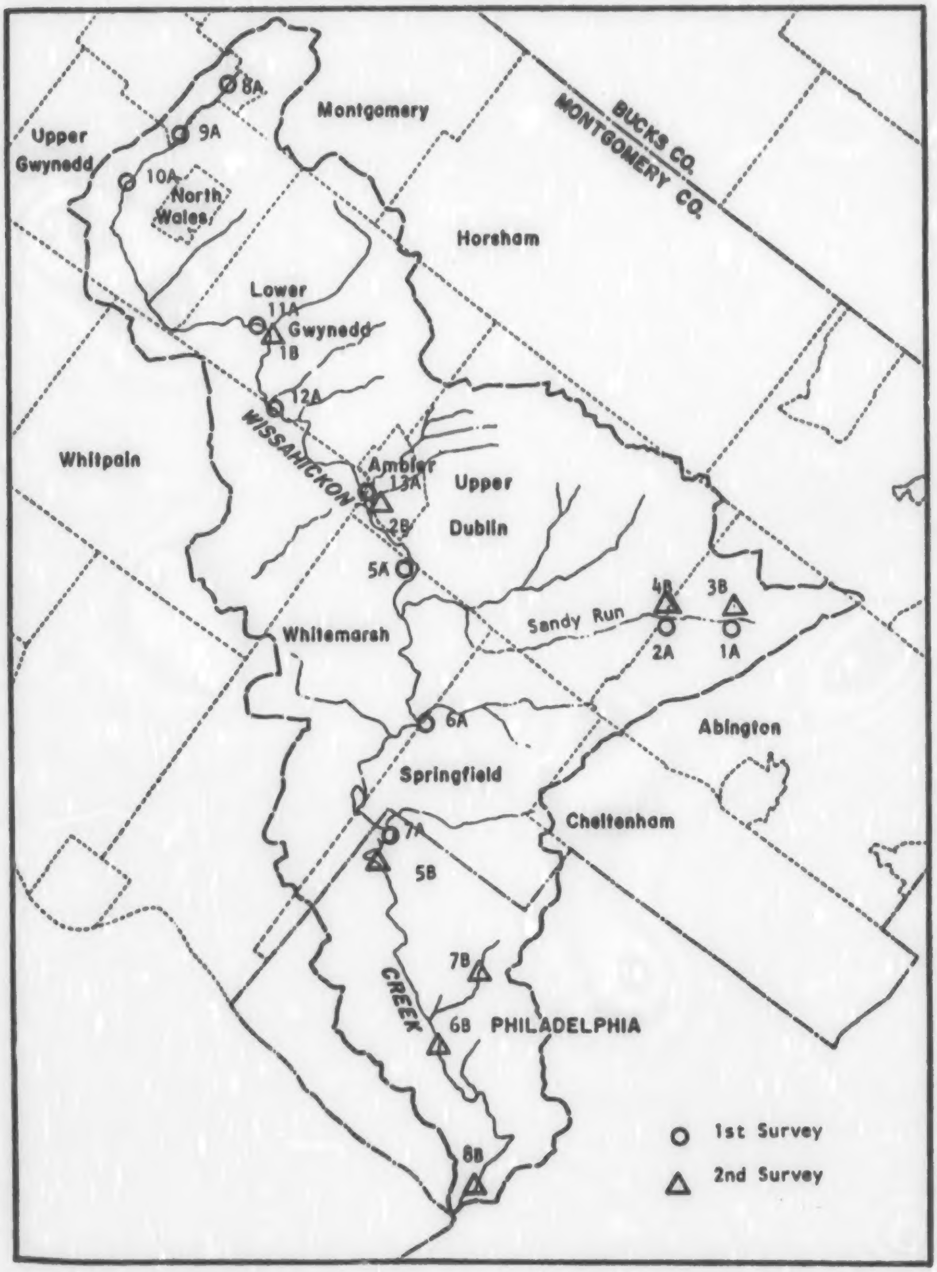
* Regional Science Research Institute, Environmental Study of the Wissahickon Watershed within the City of Philadelphia, June 1973.


8A
9A
10A
Upper Gwynedd
North Wales
Montgomery
BUCKS CO.
MONTGOMERY CO.
Horsham
Lower Gwynedd
11A
1B
12A
WISSAHICKON
Whitpain
Ambler
13A
2B
Upper Dublin
5A
4B
3B
Sandy Run
2A
1A
Whitemarsh
6A
Abington
Springfield
Cheltenham
7A
5B
7B
CREEK
6B
PHILADELPHIA
8B
1st Survey
2nd Survey

Source: Betz Environmental Engineers, Inc.

FIGURE 6

MAP OF SURVEY SITES

TABLE 7

SUMMARY OF FIRST WISSAHICKON CREEK SURVEY

Date: January 11, 1977

Weather: Clear, Temp. 20°F, Wind 10-30 mph

Field Crew: C. Gabriel and R. Kimball

Site #1A Sandy Run - Susquehanna Road Bridge

Channelized stream with development extending to the banks in some places. Mostly one-quarter-acre lots, single family residential type. Parks and ball field along portions of Sandy Run. Numerous stormwater overflows noted along banks, which would tend to negate the buffer effects of the open spaces.

Site #2A Sandy Run below Abington Sewerage Treatment Plant - Limekiln Pike Bridge

New residential area along banks now under construction (possible sediment problem). Numerous stormwater overflows along banks. Stream had strong odor of sewage. General topography is rolling hills. Again, parks and golf course along banks but numerous overflows too. Foam was noted below a small impoundment; may be caused by sewerage treatment plant effluent.

Site #5A Wissahickon Creek above Confluence with Sandy Run near Germantown Academy

Channelized stream, wooded areas along both banks. Numerous undeveloped areas along this reach of the stream. Overflows from academy noted. Stream appeared to be about 60 feet wide. High color concentration noted.

Site #6A Wissahickon Creek at Confluence with Sandy Run near Lafayette and Joshua Roads

Wooded areas adjoin both streams. Sparse development, mostly single family residences. Both streams appear to be slow moving, about 60 feet wide, with noticeable murky color. Topography is gently rolling hills.

Site #7A Wissahickon Creek at Bells Mills Road Gage

Steep wooded banks, still relatively slow moving stream with noticeable color. No overflows noted. Large deposit of sediment in central channel upstream of gage. Noticeable odors.

Site #8A Headwaters Area of Wissahickon Creek at Knapp Road Bridge in Lansdale

Single family residential development (one-third-acre lots) throughout this area. Parks along stream bank but numerous stormwater overflows noted under bridges and along banks. Topography is relatively flat.

Site #9A Wissahickon Creek at Hancock Road Bridge - Lansdale

Single family development (one-quarter-acre lots) throughout this reach. Development extends to banks. Overflows and other pipes visible. Topography still generally flat. Could be a lot of residential runoff from this area. (Both residential and commercial from nearby shopping center).

Site #10A Wissahickon Creek near Sumneytown Pike Bridge in Upper Gwynedd

Wetlands border this stretch. Pipes from nearby shopping center extending from bank. Also, a pipe apparently from a pumping station is discharging to stream. This reach susceptible to residential and commercial runoff.

TABLE 7 (continued)

Site #11A Wissahickon Creek at Rt. 202 Bridge in Lower Gwynedd

Wooded banks, rural countryside, some agriculture in this reach. Stormwater drains noted at base of bridge, probably from highway catch basins. Channel wider, maybe 70 feet.

Site #12A Willow Run near Pennlyn-Blue Bell Pike

Wooded banks - sparesely developed area, mostly one-half-acre lots, single family, residential. Stream fairly wide (50-60 feet) mostly rural countryside.

Site #13A Wissahickon Creek at Ambler Bridge - Ambler

Wooded banks. A large mound of mineral wastes (reported to be asbestos wastes) on east bank appears quite accessible to stream. Interceptor running along west bank. This area could produce substantial runoff, especially from the dump.

Results and Conclusions

1. The Wissahickoen watershed is comprised primarily of suburban residential developments, and some commercial development and limited industrial development. There are also significant undeveloped and open areas in the watershed, with some forests and farmland near the headwater portions.

2. The stream networks comprising Wissahickon Creek and Sandy Run are fairly well channelized. Frequently, a strip of open land, parks or wooded land borders the streams, acting as a buffer zone against runoff. However, numerous stormwater overflows can be seen along the banks. These overflows would tend to negate the beneficial effects of the buffer zones.

3. Portions of the stream displayed large sediment deposits which produced a strong organic odor.

provide a preliminary assessment of land uses exhibiting the potential for generating significant nonpoint source loads and to assess water quality problems. The investigation studied construction sites, storm sewer outfalls, use of buffer strips and use of controls to restrict nonpoint source runoff. Before conducting the survey, steady-state water quality model results and reports of biological studies of the stream were examined to provide an insight into probable areas of concern. On the basis of these preliminary analyses and knowledge of existing construction site locations, the survey sites were chosen.

3. Second Survey

The second survey was performed on March 24, 1977, two days after a rainfall of approximately 2.0 inches. Figure 6 also presents a map of the survey sites. These survey sites were selected on the basis of (1) potential problem areas uncovered in the first survey; (2) results of further data analysis; and (3) suspected areas of concern revealed by information gained from applying the mass balance analysis. The timing of the survey was purposely chosen: two days after a significant storm when the water level of the stream was still high. Assuming that the water level would have subsided to near steady-state conditions approximately five days later, a third, more limited survey would have produced greater insight into the effects of stormwater damage of sediment and nonpoint pollutants on stream biological conditions. Time and budget constraints prevented such a survey. A summary of the findings is presented in the following paragraphs.

4. Summary of Second Wissahickon Creek Survey

Date:	March 24, 1977
Weather:	Clear, Temp. 50°F, Wind 10-30 mph, Rainfall March 22, 1977 1.97 inches, recorded at Phoenixville
Stream Flow:	Higher than normal, but subsided substantially from peak
Field Crew:	C. Gabriel and J. White

Site #1B Headwater Area

The headwater area above known point discharger is biologically unproductive, but does not appear to be seriously affected by nonpoint source pollution. The main reason for this conclusion is the absence of siltation in the area (see Photo 1). The probable reasons for the low productivity is the intermittent flow of the stream in the headwaters and possible scouring from a recent storm (scouring would be increased by nonpoint source runoff).

Photo 1 - Wissahickon Creek Headwater Area (Site 1B)

Site #2B Ambler Area

Downstream, in the Ambler area, the stream does not appear to be seriously affected by nonpoint source pollution. Invertebrate diversity and algae growth did not appear to be reduced and invertebrate organisms characteristic of good water conditions were present. The mainstream does not appear to have a siltation problem; however, a feeder stream showed evidence of significant siltation (as shown in photos 2 and 3). It was obvious that heavy siltation loads were

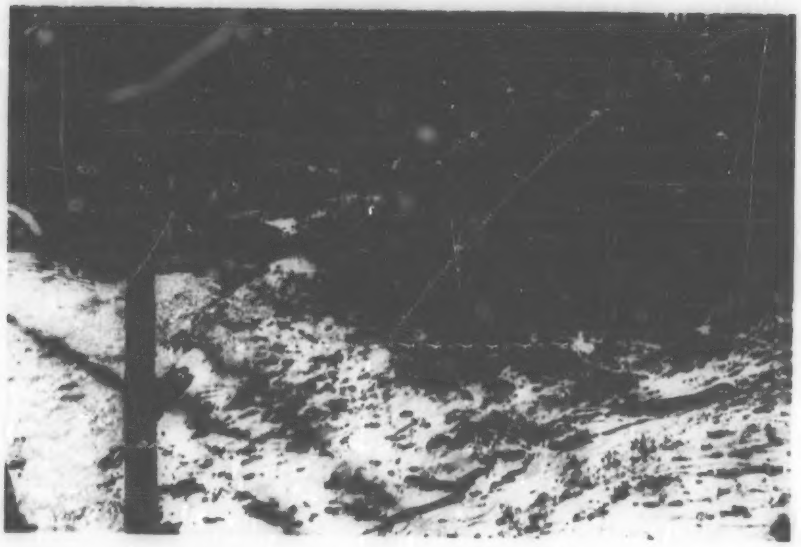


Photo 2 - Silted Tributary to Wissahickon, near Ambler

Photo 3 - Silted Tributary to Wissahickon below Ambler received by the mainstream of the Wissahickon Creek and were transported further downstream.

A second noteworthy fact was a large pile of residue of asbestos from a nearby plant. Additional waste asbestos is no longer stored there but there is evidence that the existing pile runs off to the stream (see photos 4 and 5).

Photo 4 - Asbestos Pile at Ambler; Wissahickon Creek in Foreground

Site #3B Sandy Run Upstream from Sewage Discharge

The Sandy Run tributary upstream from the known sewage discharge appeared to be nutrient enriched. Algae growth appeared relatively thick for the time of year and for following a recent heavy rainfall. The invertebrate community was greatly reduced and consisted of tolerant organisms. The source of the enrichment was not obvious and little sedimentation was apparent. However, the stream was channelized, which is probably attributable to the increased runoff from

Photo 5 - Asbestos Pile, Erosion and Runoff to Wissahickon Creek (foreground)

the heavily urbanized areas adjacent to the stream. There are large storm drains directed into the stream (see photo 6).

Site #4B Sandy Run Downstream from Sewerage Treatment Plant

Downstream from the sewage treatment plant on Sandy Run, the stream appeared heavily degraded; however, the absence of siltation indicated in this reach of the stream that non-point source pollution was not a significant problem. There

Photo 6 - Stormwater Runoff and Channelized Stream,
Sandy Run

was evidence that large sediment loads from a construction site adjacent to the stream had entered the water (see photo 7) as evidenced by washouts to the stream from the recent storm. The sediment loads were evidently transported downstream. Photo 8 shows evidence of thwarted best management practices in that a large six-foot-high pile of wood chips used to control erosion at the construction site was washed out and deposited along the stream bank.

Site #5B Wissahickon Creek-Bells Mills Road

At both the Bells Mills and Valley Green area the water was a gray, murky color and biota were reduced, indicative of a degraded environment. The stream in this reach was a series of riffles, then pools. There is evidence of sediment deposits in the pools (see photo 9).

Photo 7 - Construction Site near Sandy Run Creek (Sandy Run is located approximately 100 feet beyond excavation in background along tree line)

Sandy Run
(flows under
bridge)

Photo 8 - Wood Chips (used for Erosion Control) Washed up on Bank of Sandy Run Creek from Construction Site (see Photo 7)

Photo 9 - Sediment Deposits Below Bells Mills Road

Site #6B Ivsey Lane, below Confluence of Cresheim Creek

Below the confluence of Wissahickon and Cresheim Creeks and the dam, biological conditions appeared to be quite good where the stream flow was rapid. Invertebrate and algal conditions were indicative of good water quality and no sedimention was apparent. Above the dam, habitats were reduced and some sedimentation was apparent, indicating the dam was providing an area that collected sediment. Further below the dam was an area of collected sediment deposits from a swale running through Fairmount Park (photo 10). These sediment deposits were largely due to runoff from a site about 1/8 mile from the stream where a single home is being built (photos 11 and 12). No erosion controls were visible.

Excavated soil was piled high along the steep slopes adjacent to the swale. Philadelphia County employs what has been judged excellent land management controls for the Wissahickon Watershed. Apparently, this construction site escaped these controls because enforcement is directed mostly to larger developments. However, it can be seen that even a small construction site can cause significant nonpoint loads.

Photo 10 - Sediment Deposits (foreground) from Construction Site Transported via Swale (background)

Photo 11 - Construction Site near Ivsey Lane, Front View

Photo 12 - Same Construction Site (Rear View)
Sediment Erodes into Swale on Right
Side of Photo and is Transported to
Wissahickon as shown in Photo 10

Site #7B Cresheim Creek (Tributary to Wissahickon)

Cresheim Creek, which drains an urban area but has no point sources, appeared to be in fairly good biological condition. The invertebrate community was quite diverse, and there were no signs of storm scouring. There was evidence of a small amount of sediment (see photo 13).

Photo 13, Cresheim Creek, Some Sediment Deposits

Site #8B Mouth of Wissahickon

At the mouth of the Wissahickon and appproximately 1 mile upstream from the mouth, near a series of dams, there was heavy siltation and the biota were greatly reduced (see photos 14 and 15). Available habitats were heavily silted, which was the probable reason for the absence of aquatic biota. This appeared to be the area that received the bulk of the sediment load. Conversations with members of a canoe club located at the mouth of the Wissahickon revealed that a bar area approximately 150 feet long and 50 feet wide resulted from sediment deposits washed downstream during major storms.

Photo 14 - Wissahickon Creek Upstream of Mouth, Large Sediment Deposits and Mucky Bottom

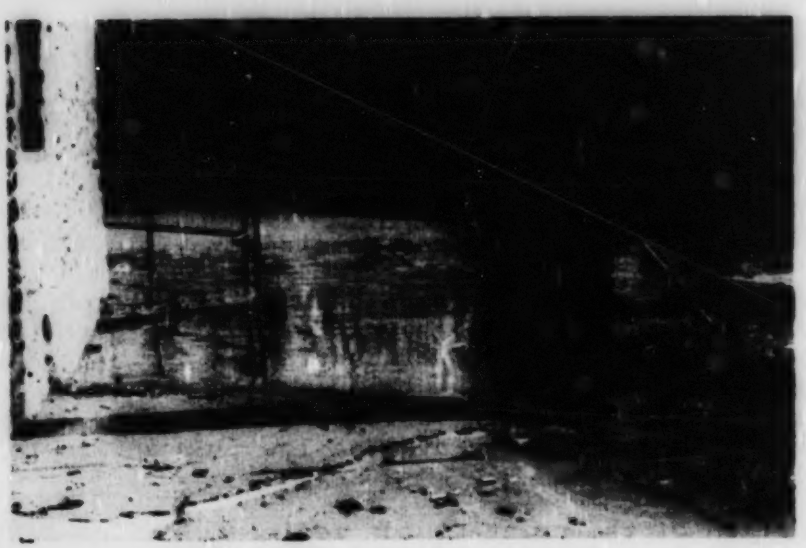


Photo 15 - Mouth of Wissahickon Creek, Very Large Sediment Deposits

5. Nonpoint Source Monitoring

Monitoring of stormwater runoff from various land uses during storms was beyond the scope of this study. Pollutant loading rates and other data, therefore, were obtained from local and regional reports, local USGS data, and the scientific literature. The sources of information and the rationale and assumptions used in this case study are explained in detail in Section F so that the user of this manual may also apply this methodology without performing a land runoff monitoring program.

It is recommended, however, that field monitoring programs be instituted to obtain localized data on loading factors. The cost of a modest field monitoring program to ascertain typical land use loading rates, in light of the ultimate costs for point and nonpoint source controls, is relatively low.

D. WATER QUALITY AND POLLUTANT LOADING ANALYSIS

Water quality, stormwater, stream flow, and rainfall data were analyzed to provide steady state pollutant loadings, calibration data, and verification data.

1. Steady-State Pollutant Loadings

Steady-state pollutant loadings were calculated from point source data and from monthly water quality data. The steady-state loading and concentration of suspended solids, BOD_5, total phosphorus, total nitrogen and total heavy metals are presented in Table 8. Values are shown in terms of concentration during average low flow and in total load in lbs/year.

A portion of the point source sediment loading settles out a short distance downstream from the wastewater discharge. These loads, which are resuspended during storm flows and washed downstream, were considered in the annual point source loading. The sediment loading includes estimated suspended solids from point sources which have settled out as benthic deposits. All the point sources discharge above

TABLE 8

EXISTING POINT SOURCE LOAD AND CONCENTRATION SUMMARY WISSAHICKON CREEK, FORT WASHINGTON(1)

Values	Parameter(2)						
	Sediment (SS)	BOD_5	NH_3	$NO_2 + NO_3$	Total Nitrogen	Total Phosphorus	Total Heavy Metals
Annual Load(3) (lbs x 10^6)	4.0	1.3	---	---	.58	.12	.021
Concentration	7.8	8.8	2.5	4.6	7.19	1.29	.26

---

(1) Derived from items 1 and 2 of Table 6

(2) Based on low flow condition of 28 cfs

(3) Includes resuspended point source loads

Source: Betz Environmental Engineers, Inc.

the Ft. Washington gauging station; therefore, the calculated point source loading is representative of total point sources in the Wissahickon Watershed.

2. Calibration Data

The United States Geological Survey (USGS) flow and sediment yield data at the Ft. Washington gauging station for water year 1968 (October 1967 through September 1968) were the most complete data available for calibration of sediment loads. Corresponding rainfall data were taken from National Oceanographic and Atmospheric Administration (NOAA) records for an adjacent watershed near North Philadelphia Airport (approximately 15 miles from the geometrical center of the Wissahickon Watershed). Table 9 presents a summary of the loading and rainfall conditions for 1968. During 1968, 12 storms yielded more than 40 tons of sediment per storm. The total sediment loading from these 12 storms which occurred during only 6.3% of the year, accounted for 15 million pounds or 94.3% of the total annual sediment loading. The annual nonpoint sediment loading at the summation point was 12.25 million pounds.

Regression analysis of sediment loading versus storm flow and monthly stream flow indicated excellent correlation with coefficients of 0.93 and 0.92 as shown in Figures 7 and 8, respectively. Figures 9 and 10 show a similar relationship of sediment load versus storm rainfall and monthly rainfall. This regression analysis exhibited acceptable correlations of 0.76 and 0.61, respectively. The rainfall correlations with sediment are believed to be less than those of flow correlations because rainfall was measured in an adjacent watershed while flow was measured within the watershed.

3. Verification Data Set

Sediment loadings from six of the storms occurring during 1964 were measured by the USGS at Ft. Washington. These data were selected to serve as the base for verification analysis. Regression analysis of the sediment loading versus storm flow, presented in Figure 11, yielded a good correlation of 0.96.

TABLE 9

SUMMARY OF STORM LOADING - WISSAHICKON CREEK, FORT WASHINGTON, 1968(1)

	Rainfall (inches)	Flow (cfs days)	Total Load (lbs x 10^6)	Nonpoint Sediment Loading (lbs)
Storm Load (12 storms)(2)	19.1	8,274	15.31	15.31(3)
Total Annual	37.85	20,329	16.25	12.25(4)
% of Storm to Annual	50.5	40.9	94.3	---

---

(1) Derived from items 3, 4 and 5 of Table 6

(2) Storms spanned 23 days or 6.3% of total days of year

(3) Slightly less than 15.31 x 10^6 lbs because most of load consisted of nonpoint runoff

(4) Nonpoint source loading is equal to total loading minus point source loading and corresponds to calibration nonpoint source loading

Source: Betz Environmental Engineers, Inc.

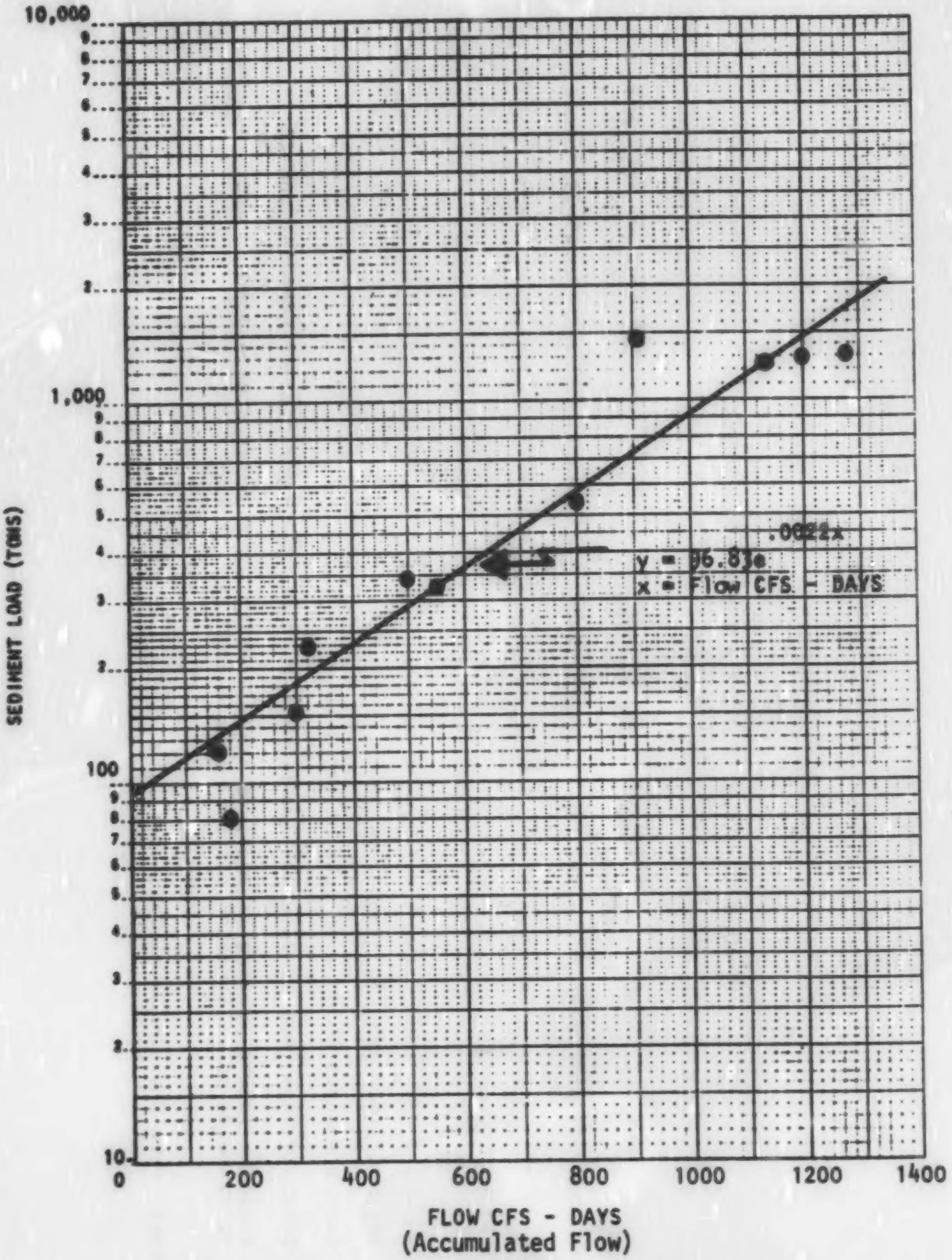


FIGURE 7

WISSAHICKON WATERSHED - SEDIMENT VERSUS STORM FLOW

WATER YEAR 1968; FORT WASHINGTON GAUGE; CORRELATION = 0.93

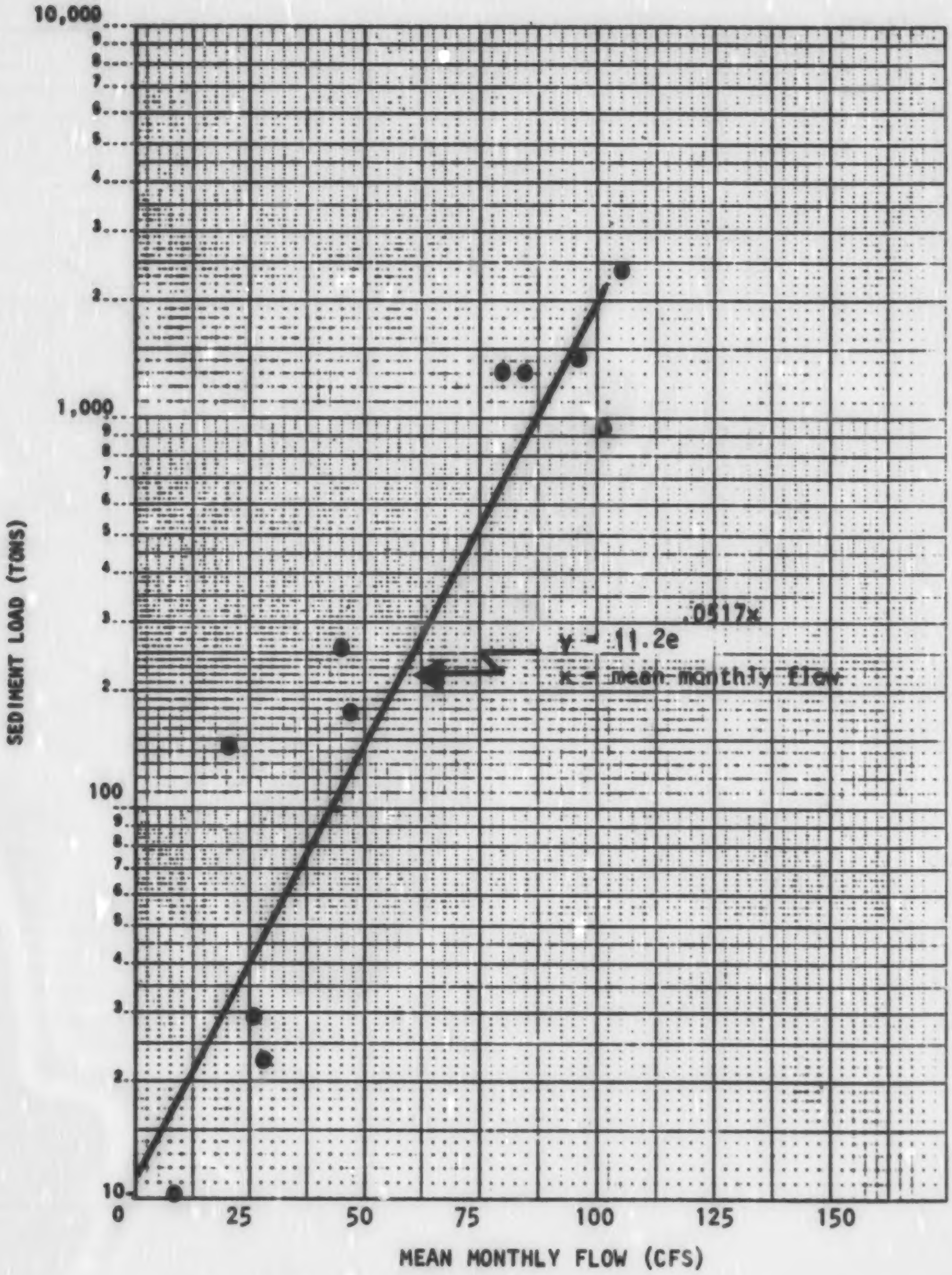


FIGURE 8

WISSAHICKON WATERSHED - SEDIMENT VERSUS MONTHLY FLOW

WATER YEAR 1968; FORT WASHINGTON GAUGE; CORRELATION = 0.92

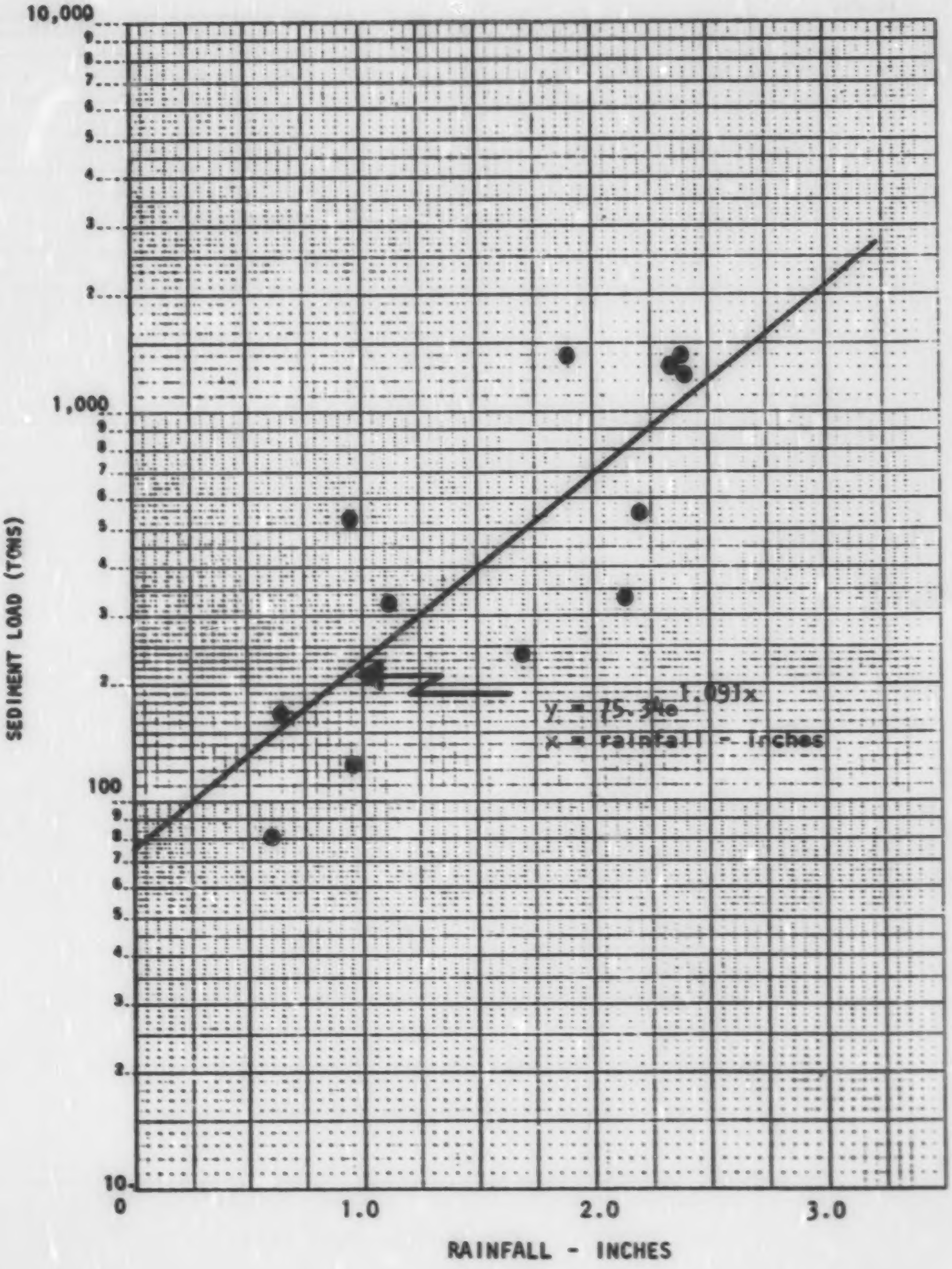


FIGURE 9

WISSAHICKON WATERSHED - SEDIMENT VERSUS STORM RAINFALL

WATER YEAR 1968; FORT WASHINGTON GAUGE; CORRELATION = 0.76

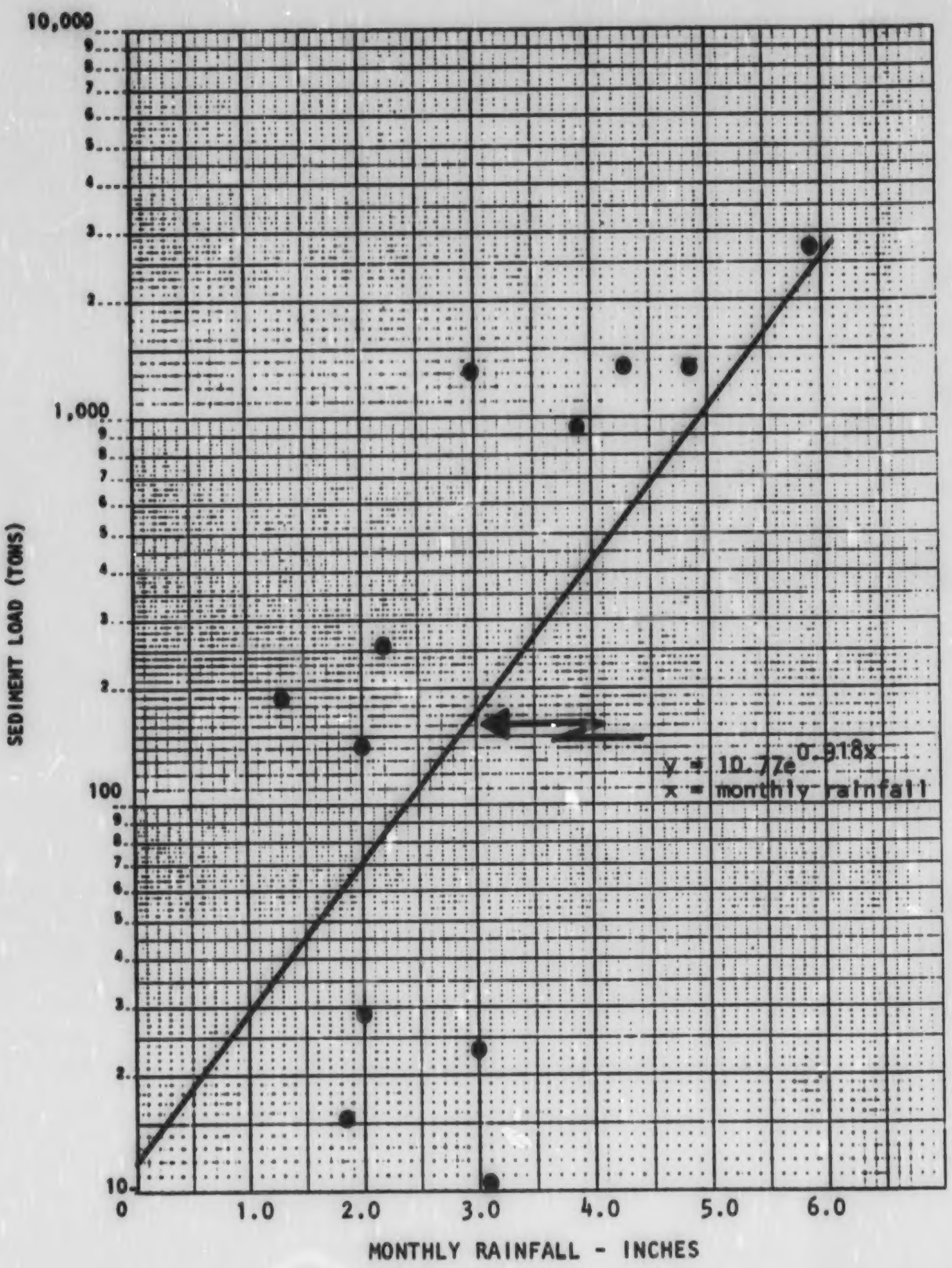


FIGURE 10

WISSAHICKON WATERSHED - SEDIMENT VERSUS MONTHLY RAINFALL

WATER YEAR 1968; FORT WASHINGTON GAUGE; CORRELATION = 0.61

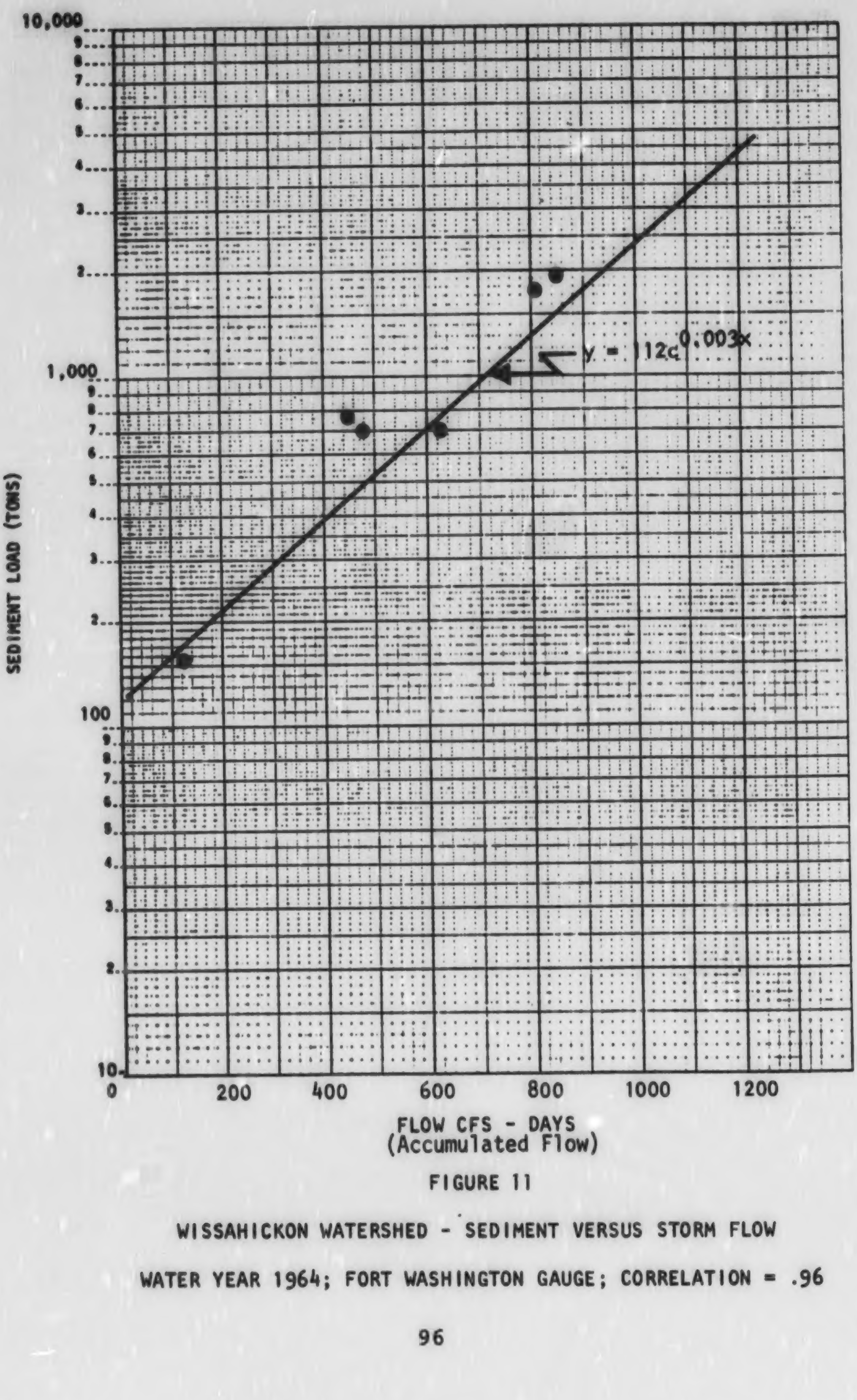


FIGURE 11

WISSAHICKON WATERSHED - SEDIMENT VERSUS STORM FLOW

WATER YEAR 1964; FORT WASHINGTON GAUGE; CORRELATION = .96

Based on the equation derived from the regression analysis, the sediment load of all of the storms for the USGS water year 1964 were calculated. This resulted in a total annual load of 13.84 million lbs/year (see Appendix C for full data set). Table 10 shows the relationship of sediment loads, rainfall and flow of the verification year 1964 and the calibration year 1968. The nonpoint source loading (total loading - point source loading) was 9.84 million lbs. This represents the verification load at summation point number one.

E. SELECTION OF SUBAREAS AND LAND USE CATEGORIES

1. Subarea Delineation

The most prominent feature of the subarea delineation is its urban-suburban interface. Most of the developed land in the study area is suburban. The southernmost portion of the study area lies in the City of Philadelphia where the Wissahickon Creek threads its way through Fairmount Park.

The primary considerations in subarea selection were hydrologic features, man-made influences on runoff drainage, and the existing land development patterns.

(A) Hydrologic Characteristics: The criteria used to delineate subareas were primarily hydrologic characteristics of the study area. Each subarea represents a drainage area to the Wissahickon Creek. Subarea segmentation is shown in Figure 12. Drainage areas M2, M3 and M4 each have creeks--the Trewellyn, Prophecy and Sandy Run, respectively--which are tributary to the Wissahickon.

Seven subareas were delineated along with three summation points. The summation points are at Ft. Washington, Bells Mills and at the confluence of the Wissahickon Creek and the Schuylkill River. Basically, all data derived from subareas M1 through M5 are summed at the Fort Washington summation point. At Bells Mills, data cover M1-M5 as well as N1. At the confluence, data include information from all subareas, including O1, which is largely Philadelphia.

TABLE 10

ANNUAL SEDIMENT LOADING, RAINFALL AND STREAM FLOW 1964 and 1968(1)

Parameter	1964 (Verification)	1968 (Calibration)	1964 (Nonpoint Source Loading)
Sediment Loading (lbs x 10^6)	13.84	12.25	9.84
Flow (cfs)	16,931	20,239	----
Rainfall (inches)	31.45	35.45	----

---

(1) Derived from items 3, 4 and 5 of Table 6 and computer printouts of mass balance shown in Appendix C

Source: Betz Environmental Engineers, Inc.

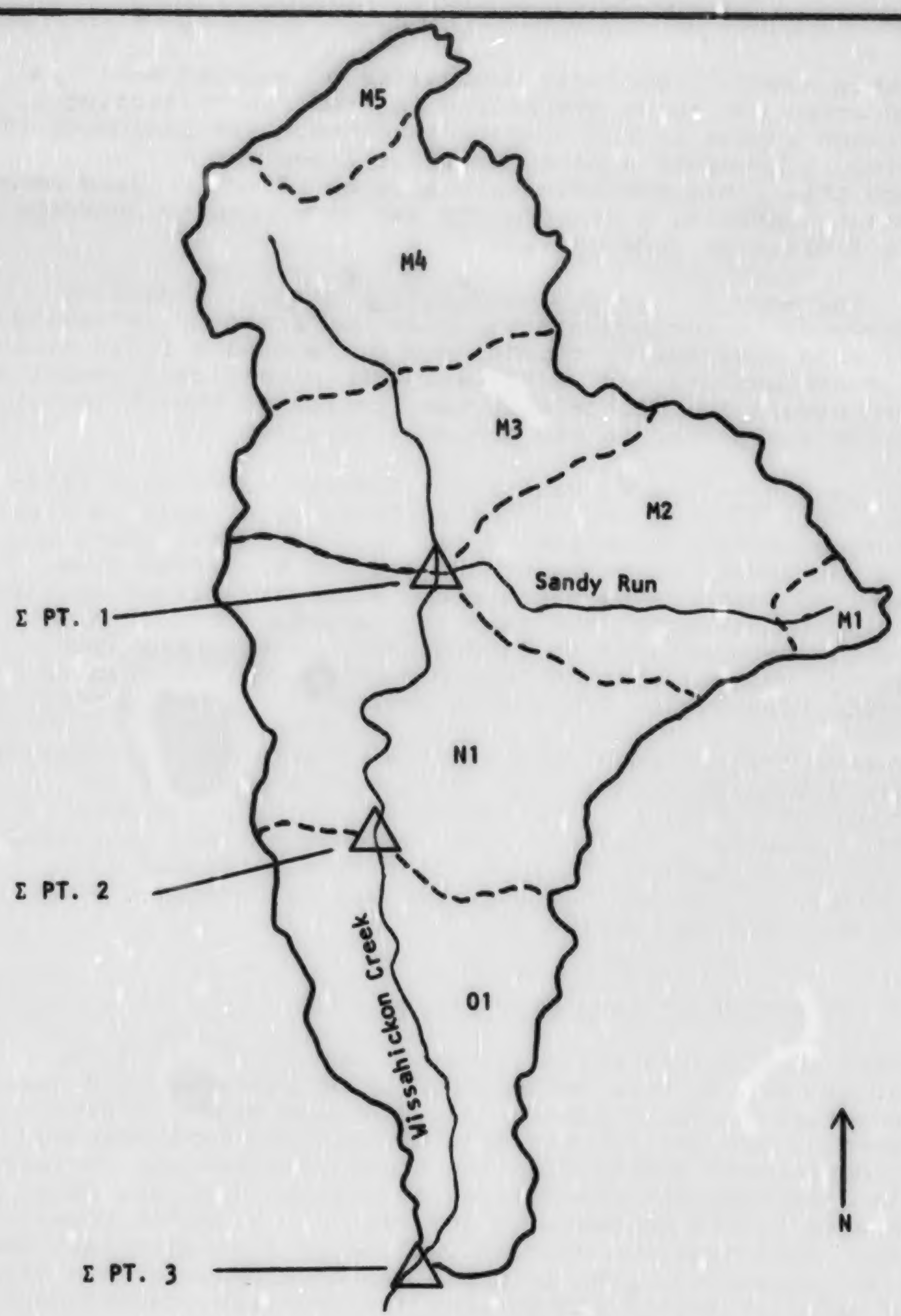

M5
M4
M3
M2
M1
N1
O1
Sandy Run
Wissahickon Creek
Σ PT. 1
Σ PT. 2
Σ PT. 3
N

FIGURE 12

WISSAHICKON WATERSHED SUBAREA SEGMENTATION

Source: Betz Environmental Engineers, Inc.

In this study, hydrologic boundaries outweighed municipal boundaries due to an overriding interest in reflecting drainage impact at the summation points. The incidence of municipal boundaries based on ridge lines was minimal. Since this would predominately have an effect on land management controls, a methodology was developed to overcome this limitation (see pp. 129 to 132).

(B) Man-Made Influences on Runoff Drainage: Existing stormwater conveyance systems were confirmed by reviewing available engineering reports and performing a field study to locate outlets and overflows. The significant extent of storm sewers in Philadelphia was the reason the Philadelphia portion was placed in one drainage subarea.

(C) Land Development Patterns: Efforts to protect Fairmount Park by the City of Philadelphia have included regulatory measures which influenced land use development and land management in the southern part of the study area. While the park has been protected since its origin by city regulatory measures, the land adjacent to the park has recently been subject to land management measures (most notably, the Wissahickon Development guide) designed to protect Wissahickon Creek from encroaching development.

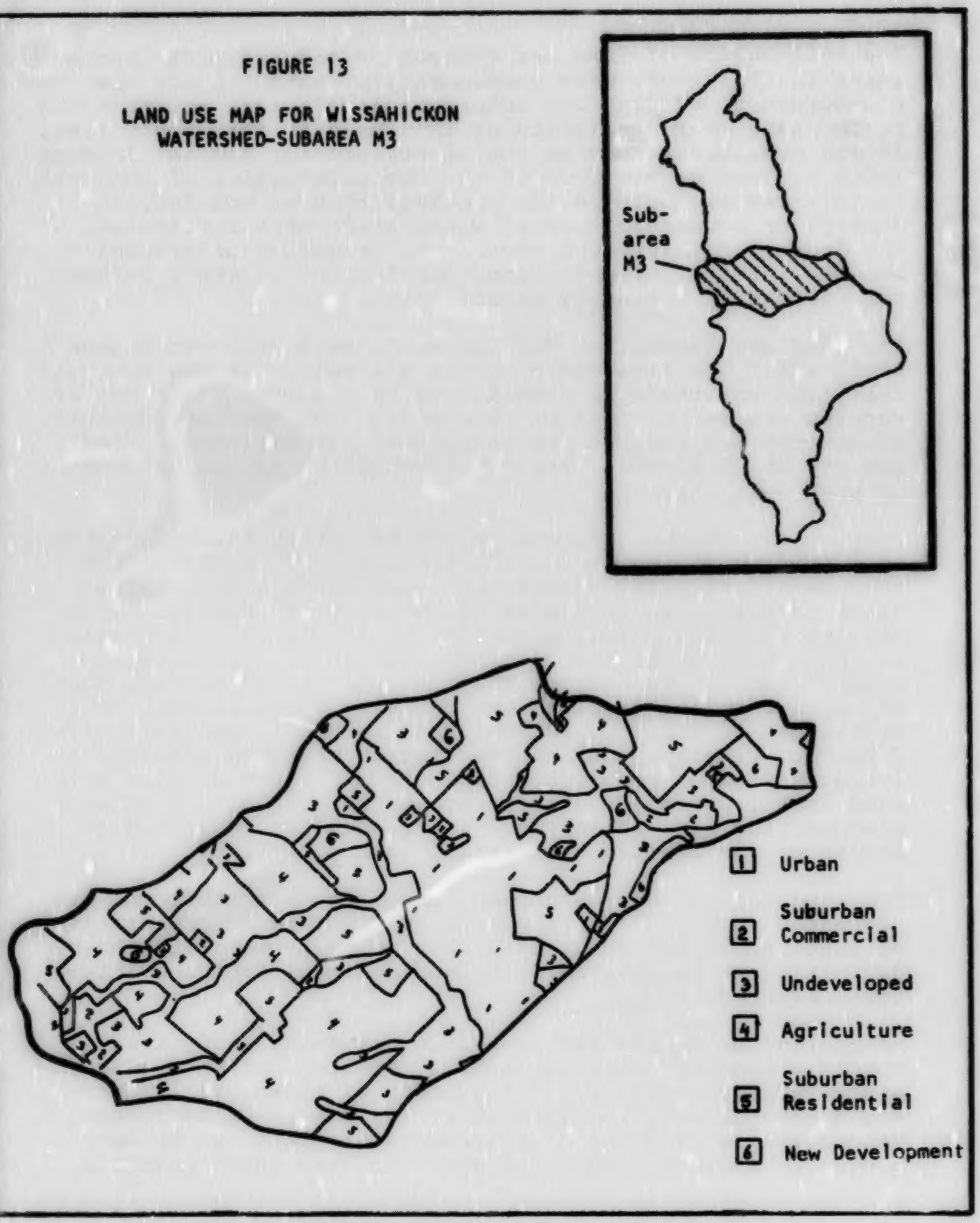
North of Philadelphia, the study area includes two smaller, older urbanized areas: the Borough of Ambler and the Borough of Lansdale. The remainder of the study area is mostly suburban, combined with agricultural and undeveloped land. An extension of higher density development from Philadelphia outward has occurred and is accounted for predominately in subarea N1.

2. Selection of Land Use Categories

Figure 13 illustrates the level of detail required for a land use map in this methodology by delineating land use categories found in subarea M3. In this study, a prescreening examination was made of land use maps prepared by the Montgomery County Planning Commission and the Philadelphia City Planning Commission, as well as land use data prepared by the Delaware Valley Regional Planning Commission. This provided a broad outline of the major land uses to be considered. The land use map developed for the study was based on aerial photography and USGS topographic maps. The method used to develop the land use map is presented in Appendix G.

FIGURE 13

LAND USE MAP FOR WISSAHICKON WATERSHED-SUBAREA M3


Sub-area M3
1 Urban
2 Suburban Commercial
3 Undeveloped
4 Agriculture
5 Suburban Residential
6 New Development

Source: Betz Environmental Engineers, Inc.

The delineation of land use categories and sediment loading rates in this study were complementary tasks. Since the pre-screening of land use information made more apparent the predominant characteristics of land uses in this study area, it was possible to review the literature for similar loading rates of land uses. Some of the characteristics of interest in this review included the specific type of housing, industry, or commercial use to which loads were attributed; the degree of impervious cover; the frequency of rainfall; and the level of urbanization, population, or other parameter indicating intensity of activity.

The land use categories for the study area were not chosen until after the literature review was made. It was apparent that land use could be categorized in a number of forms, by varying the definitions of categories. As much as possible, an attempt was made to use compatible definitions of land use for which loading rates were contained in the literature by such definitions.

There were a number of constraints in categorizing land use and arriving at sediment loading rates. In the first place, the characteristics of land uses associated with loading rates in the literature were often not well identified, leaving open the question of how applicable the rates were to this study area. Second, the available literature included studies performed throughout the United States, most of which were not readily applicable to the Philadelphia region due to soil, topographic and rainfall condition difference. Finally, most of the studies measured loadings in lbs/acre/year or some convertible form. Those studies which used another form of measure such as concentrations without accompanying flow which could not readily be converted to lbs/acre/year limited the overall choice of values.

The land use categories chosen, based on this approach, are presented in Table 11. These categories are representative of land use in the study area, but general enough in their definition to be equated with loading rates from the literature reviewed.

Monitoring of stormwater runoff to determine study area specific loading rates was beyond the scope of this case study. Undoubtedly, field inventory of stormwater runoff would have greatly enriched this data base. It is recommended that monitoring of representative land use be employed to achieve study area specific data where possible.

TABLE 11

DEFINITIONS OF LAND USES

Land Use Category	Description	General Assumptions
Cropland	Land currently in use for agriculture	Less than 10% impervious cover Land periodically turned over Contour plowing practiced where required by slope No on-going management in proximity to stream Most farms < 100 acres (max. about 500 acres)
Urban Mix	Mix of industrial, commercial and multi-family residential	lots < 1/4 acre 50-75% impervious cover
Suburban Commercial	Discrete pockets of commercial activity such as strip development, malls, industrial parks, schools, hospitals, etc.	variable lot size 75+% impervious cover
Suburban Residential	Mostly single family residences	lot size > 1/4 acre but generally smaller than 1 acre 10-50% impervious cover
Forest & Undeveloped	Wooded areas, parks, fields and other undeveloped vegetated regions	less than 10% impervious cover less than 1 structure per acre
New Land Development	Land formerly in agriculture or undeveloped categories currently undergoing residential or commercial construction	variable site size remains in category up to maximum 4 years land use management varies by municipality considerable sediment loss potential

(A) 1968 Land Use: In this study, water quality and non-point source data were most complete for 1968; therefore 1968 was selected as the base year for analyzing existing conditions including land use and raw loading rate determination.

Land use categories used for the study area are presented in Table 11. The categories include cropland, urban mix, suburban commercial, suburban residential, forested undeveloped, and new land development.

Urban mix includes an integration of residential, commercial, industrial, public and institutional land uses at a sufficient density to indicate the central core of an area. New land development was delineated as a separate land use category because of its high erosion potential.

A summary of land use by subarea based on 1968 data is presented in Table 12. Forest and undeveloped land accounted for the highest percentage (36.2%) of the 40,960 acres in the study area. Urban mix accounted for 26.9% and all suburban categories accounted for 20.2% of the total land.

(B) Land Use Projections: Projections of land acreage for each of the six categories were derived for the years 1985 and 2000. This information is presented in Table 13.

Land use data for the year 2000 were based on population forecasts of the Delaware Valley Regional Planning Commission (DVRPC). The DVRPC data were available by minor civil division. The data were used to obtain an estimate of population increase for each subarea. The specific land use changes in each subarea were based on the following assumptions: 50% of the population increase would settle in multi-family units at a density of 25 persons/acre; 50% would settle in single family units at a density of 10 persons/acre.

In 1970, the U.S. Bureau of the Census in Detailed Housing Characteristics (Pennsylvania) reported for Montgomery County, Pennsylvania (where almost all new residential development in the study area will most probably occur) a split of 60% single family units--40% multi-family units for 1970. However, housing unit construction trends nationwide (Source: Joint Center for Urban Studies of M.I.T. and Harvard University, February 1975) indicated that single-

TABLE 12

WISSAHICKON CREEK CASE STUDY
LAND USE BY SUBAREA(1)

Land Use (1968)	Subarea (Acres)							
	M1	M2	M3	M4	M5	N1	O1	Total
Urban	1231	1079	1208	594	683	2880	3366	11,041
Suburban Commercial	35	659	195	367	278	310	222	2,066
Suburban Residential	117	1349	1521	1979	363	638	231	6,198
Undeveloped	408	2531	1813	3080	290	4071	2628	14,821
Agriculture/crop	0	645	1857	2825	53	126	42	5,548
New Development	58	324	157	209	204	167	167	1,286
Total 1968	1849	6587	6751	9054	1871	8192	6656	40,960

---

(1) Derived from sources 12, 16 and 17 in Table 6

Source: Betz Environmental Engineers, Inc.

TABLE 13

LAND USE PROJECTIONS - WISSAHICKON WATERSHED

Land Use	Year	Subarea (Acres)						
		M1	M2	M3	M4	M5	N	O
Urban	1985	1251	1174	1268	671	730	2935	3395
	2000	1270	1268	1328	748	776	2990	3423
Suburban Commercial	1985	61	785	284	474	333	388	250
	2000	87	911	373	581	377	465	278
Suburban Residential	1985	150	1507	1635	2116	419	738	278
	2000	183	1664	1749	2252	474	837	325
Forest and Undeveloped	1985	363	2456	1698	2945	254	3968	2626
	2000	298	2291	1608	2840	233	3867	2628
Agriculture/Crops	1985	0	527	1767	2719	27	63	21
	2000	0	405	1652	2585	0	0	0
New Land Development	1985	24	138	99	129	108	100	86
	2000	11	48	41	48	11	33	4

Source: Betz Environmental Engineers, Inc. and Delaware Valley Regional Planning Commission, year 2000 population forecasts family construction accounted for 55% of all units in the 1965-1969 period and 47% for the 1970-1973 period. Based on these trends, the percent of unit types previously cited were applied for this projection.

Additional acreage counts were determined for urban, suburban residential, and suburban commercial, taking into account that approximately ten percent of all additional developed acreage was considered to be new land development in the year 2000. The increases in the above categories were compensated by an equal loss of land in the agriculture/crop and undeveloped land categories.

Land use for the year 1985, selected as a mid-point between 1968 and 2000, was developed based on a straight-line extrapolation of acreage counts for the categories of urban mix, suburban commercial and suburban residential. The other categories were similarly changed to balance loss of land to development. The value of the 1985 land use projection was to illustrate how the methodology could be used to assess sediment reduction capability of control systems over time, given changing land use conditions. It is important to qualify, however, that land use projection was not the intent of this study. More sophisticated methods of projection than that applied here should be used when attempting to assess control system capabilities over such periods of time.

F. DETERMINATION OF RAW LOADING RATES

The land use runoff sediment loading rates are based on the modified runoff equation and include the following factors:

Raw runoff rates (K)
Rainfall factor (R)
Slope length factor (LS)
Sediment delivery ratio (SD)
Natural controls (P)
Land Management Controls (K_2)

A list of typical loading ranges (lb/acre/yr) was developed from a general literature search, the purpose of which was to determine the characteristic orders of magnitude and to rank the land uses based on typical loading ranges. The following ranges were found:

Land Use	Sediment Loading Range, lb/acre/yr.
Urban Mix	174 - 6,617
Agricultural (crops)	255 - 3,750
Forest and Undeveloped	40 - 117

However, these rates often included some or all of the modifying factors listed above. As such, many of the values found in literature are low.

The range of rates found for both urban mix and agriculture are so wide as to render selection of an average runoff rate of questionable value. It is believed that the widely varying rates found in the literature search resulted from the varying degree of intensity of land use (degree of urbanization and farming) and from the fact that many of the runoff values reported implicitly included many of the modifying factors listed above and as such were much lower than the characteristic raw runoff rate. Therefore, the raw runoff rate of each typical land use was determined through selective use of literature rates. Only those literature values for similar land use intensity and geographical and climatic conditions were used. In addition, estimates were made as to the effect of runoff rate modifiers and raw runoff rates back-calculated.

1. Urban Mix Loading Rate

Since urban runoff data were not available for the study area, selection of a raw loading rate was based on the following approach developed in the EPA publication, "Report on Loading Functions for Assessment of Water Pollution from Non-point Sources" (November 1975):

(A) Selection of a region-wide urban loading rate (lbs/curb mile/day) from data collected from a nation-wide study. A mean loading rate of 103 lb/curb mile/day of raw runoff was reported for the northernmost portion of the southeast climatological region. However, since the City of Philadelphia and older urban areas such as Ambler and Lansdale comprised most of the study area's urban land, it was decided to use a rate twice as great (206) as the documented value of 103 for this study area to account for the greater intensity of urban activity exhibited here.

(B) Estimation of the average curb mile density (curb miles/acre) based on a graphical solution relating curb mile density to population density (see Appendix I for graphical solution and source). The population density of the Ambler area was 14.8 people per acre based on the 1970 census. This population density reflects a curb density of 370 ft/acre (0.07 mile/acre).

(C) Using the factors generated in the two previous steps, compute a projected annual loading rate:

$$K = (206\ \text{lb/curb mile/day})(0.07\ \frac{\text{curb mile}}{\text{acre}})(365\ \text{days/yr})$$

$$= 5{,}263.3\ \text{lb/acre/yr.}$$

The value generated above was then compared with the list of typical loading ranges from the literature. This list (page 108) showed a range of 174-6617 for the urban mix category. In comparing the generated value to the literature values, a determination was made, based on an urban characteristics of the study area, to choose an approximate value of 6000 lb/acre/year.

2. Agricultural Loading Rate

Since runoff data were not available for the study area, the cropland loading rate was based on an analysis of soils association maps for Montgomery and Philadelphia Counties. Typical soils in the study area are comprised of shale and sandstone with some clay deposits. The soils have the following properties:

- Permeability range: slow to moderately rapid.
- Erosion hazard: severe where slopes exceed 7%.
- Overall runoff rate: rapid.

A draft watershed work plan for the Wissahickon (Montgomery County Soil and Water Conservation District, October 1965) reported that the annual sediment production in the watershed is generally high, averaging 4 acre feet per square mile (32,670 lb/acre/yr). Because of the high potential for runoff, the extreme end of the agricultural range (see page 108) was selected (3,750 lb/acre/yr). This value was rounded off to 4,000 lb/acre/yr.

3. Forest Loading Rate

Little forest runoff data were available on which to make a selection; however, the literature search produced a raw sediment loading range in the low hundreds. To be on the conservative side, a rate of 500 lb/acre/yr was selected.

4. Suburban Commercial and Suburban Residential Loading Rates

The aid of literature values for loading rates of these two categories was not possible since only one value could be found for each of these land use categories and each was felt to be too low for this study area and probably not representative of a range for these categories. Since, in addition, specific runoff data were not available for the study area, the sediment loading rate for these two land uses was determined to be less than the urban mix or cropland rates, but higher than the forest. A loading rate of 1000 lb/acre/yr was selected for suburban residential. A rate of 4000 lb/acre/yr was assigned to suburban commercial to reflect the large amount of impervious surface and the on-site commercial activities.

5. New Land Development

Extreme variations in raw sediment loading rates for land under new construction were found in the literature. In many instances, the estimated rate was as much as 100 times that for undeveloped, undisturbed land, with extremes ranging to 60,000 lb/acre/year. A conservative estimate of 30,000 lb/acre/day was selected; this represented a 6000% increase over the rate applied to undeveloped land.

G. DETERMINATION OF RAW LOADING RATE MODIFIERS

1. Rainfall Factor (R)

The rainfall factor was calculated using the ratio of total rainfall of a given year to total rainfall of the calibration year, or alternately, the ratio of total flow (cfs-days) of a given year to the total flow of the calibration year. Both methods were utilized in the Wissahickon Watershed Case Study and are shown for comparison purposes. They are summarized in Table 14. The calibration year rainfall factor is normalized to 1.0; others are related to it.

2. Slope Length Factor (LS)

The slope length factor for each land use within each subarea is determined by a simplified three-step process: (1) determine steep-slope factors, (2) determine mild-slope factors, and (3) determine composite weight averaged slope length factor.

(A) Steep Slope Factors: The areas with slope gradients greater than 12% were provided in a gradient map overlay shown in Figure 14. Steep slope factors were calculated as follows:

- This steep slope overlay was superimposed with the land use categories map and USGS Topographical maps.
- Examination of steep slope areas revealed an average slope length to be approximately 200 feet.
- The average of the slope grades in excess of 12% was approximated at 15% grade.
- An average slope length factor of 3.5 was derived from the criteria presented in Figure 15. This factor was multiplied by the area of each land use overlaying steep slopes.

TABLE 14

RAINFALL FACTOR (R) FOR WISSAHICKON WATERSHED(1)

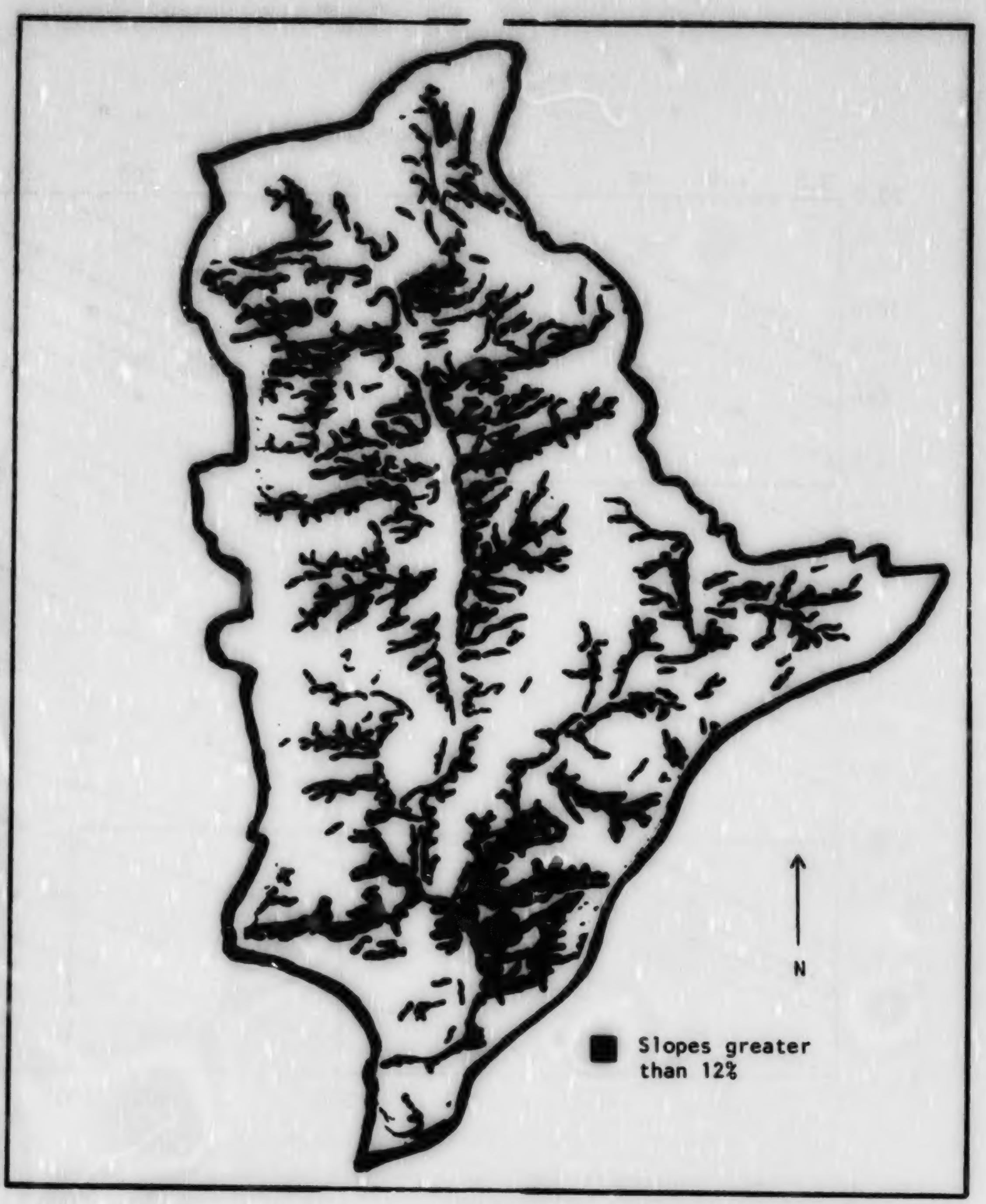
Data Set/Year	R - (Rainfall Base)		R - (Flow Base)	
	Total Rainfall (inches)	R Factor	Total Flow CFS - Days	R Factor
Calibration Year/1968	35.45	1.0	20,239	1.0
Verification Year/1964	29.9	0.85	16,239	0.83
Projections/1985-2000(2)	35.45	1.0	20,239	1.0

---

(1) Derived from items 3, 4 and 5 of Table 6.

(2) Flows and rainfall of projections were assumed to equal those of the calibration year. Projections can be run for any desired or predicted rainfall.

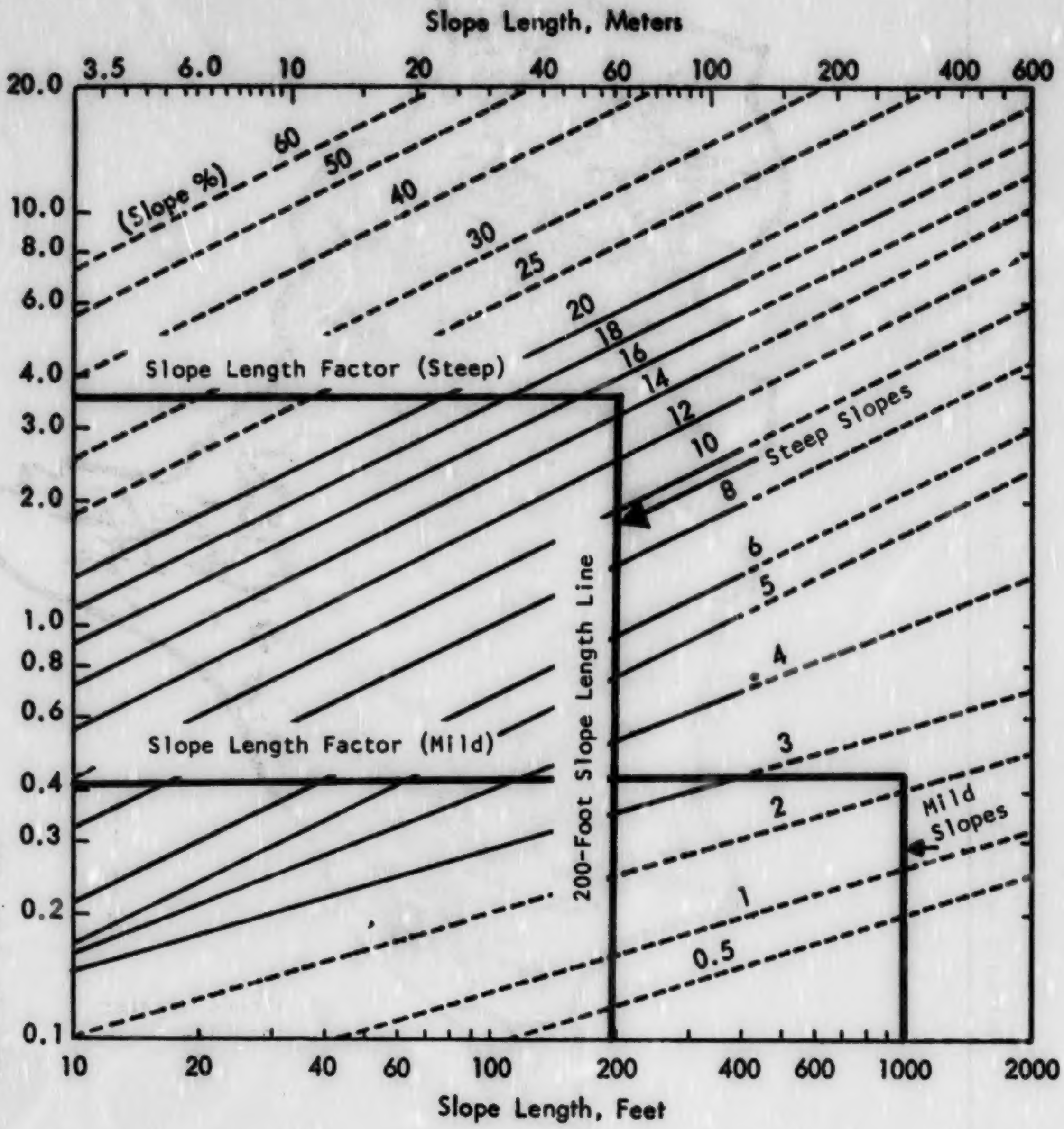
Source: Betz Environmental Engineers, Inc.


N
■ Slopes greater than 12%

Source: Delaware Valley Regional Planning Commission, 1975

FIGURE 14

CRITICAL SLOPES MAP FOR THE WISSAHICKON WATERSHED



Source: EPA, 1975

The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available.

FIGURE 15

SLOPE LENGTH DETERMINATION CRITERIA

B. Mild Slope Factor: All land use areas not overlaying steep slopes were found to be on relatively flat grounds. They were estimated to have a slope of 2.5% grade and an average length of 1000 feet. These estimates were made by observing topographical grade line features. A slope length factor of 0.4 was derived from the criteria previously shown in Figure 15. This factor was multiplied by the area of land use overlaying mild slopes.

C. Weight Averaging: The weight averaged slope length factor (LS) for each land use was calculated as follows:

$$\text{LS (Weight Averaged)} = \frac{(\text{Steep Slope Factor} \times \text{Steep Area}) + (\text{Mild Slope Factor} \times \text{Mild Area})}{\text{Total Land Use Area}}$$

The resulting slope length factors employed for all land uses/subareas are shown in Table 15.

3. Sediment Delivery Ratio

The sediment delivery ratio for each land use within each subarea was determined by a four-step process:

- Determine runoff transport potential
- Determine drainage densities
- Determine sediment delivery of each hydrologic group
- Determine weight averaged sediment delivery ratios

(A) Runoff Transport Potential: The runoff transport potential of soils was determined by:

(1) Developing a map overlay of soils runoff potential based on hydrologic subdivision of soils as presented in the soil survey publications of the U.S. Department of Agriculture for Montgomery and Philadelphia Counties (see Figure 16). The hydrologic descriptions of runoff potential were previously presented in Section III under description of methodology for sediment delivery ratio.

TABLE 15

SLOPE LENGTH FACTORS - WISSAHICKON WATERSHED(1)

Subarea	Slope Length Factor (LS)					
	Urban	Suburban Commercial	Residential	Cropland	Undeveloped	New Development
M-1	0.6	0.4	0.9	0.4	0.6	0.6
M-2	0.6	0.6	0.6	0.5	0.7	0.6
M-3	0.5	0.4	0.5	0.5	0.6	0.5
M-4	0.5	0.4	0.5	0.5	0.5	0.5
M-5	0.4	0.4	0.4	0.4	0.4	0.4
N1	0.6	0.6	0.6	0.6	0.7	0.6
O1	0.6	0.6	0.8	0.4	1.0	0.7

---

(1) Derived from items 8, 16 and 17 of Table 6 and criteria presented in Figures 14 and 15

Source: Betz Environmental Engineers, Inc.

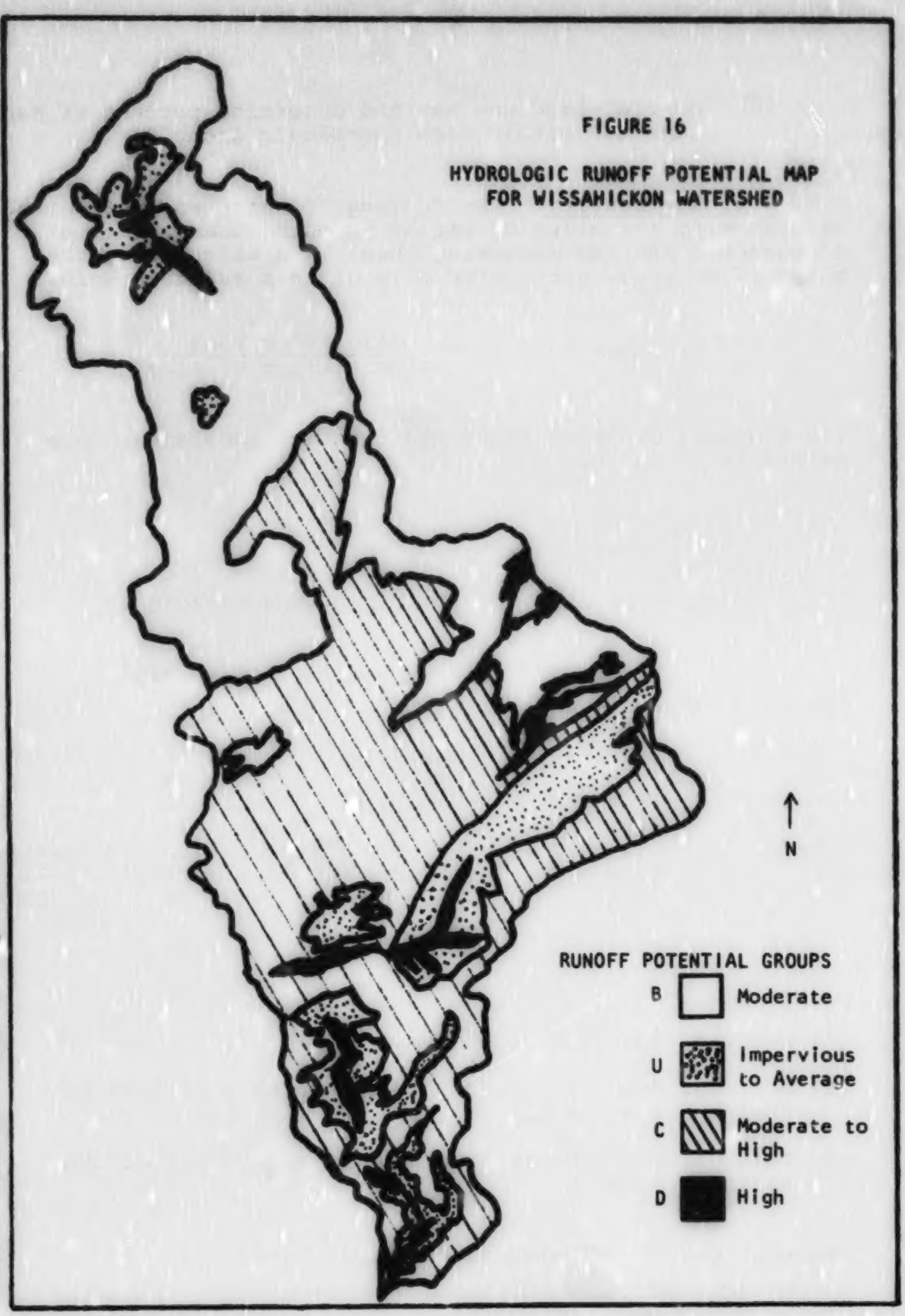

RUNOFF POTENTIAL GROUPS
B ☐ Moderate
U ▨ Impervious to Average
C ▨ Moderate to High
D ■ High
N

FIGURE 16

HYDROLOGIC RUNOFF POTENTIAL MAP FOR WISSAHICKON WATERSHED

Source: Betz Environmental Engineers, Inc.

(2) Overlay land use map and determine percent of each land use within each hydrologic group.

(B) Drainage Density: The drainage density was determined by measuring the miles of stream in each subarea (using topographic map and measuring wheel) and calculating the miles of drainage per square mile of area as shown below:

$$\text{Drainage Density} = \frac{\text{miles of stream}}{\text{square miles of area}}$$

The measured drainage densities for each subarea are presented in Table 16.

TABLE 16

DRAINAGE DENSITIES - WISSAHICKON WATERSHED(1)

Segment	Stream Miles	Drainage Area mi^2	Drainage(2) Density	1/DD(3)
M-1	2.7	2.88	0.94	1.063
M-2	14.8	10.30	1.44	.69
M-3	18.4	10.55	1.74	.57
M-4	20.3	14.5	1.43	.70
M-5	4.45	2.92	1.52	.66
N	15.9	12.80	1.24	.81
O	13.3	10.39	1.28	.78
		Mean	1.37	.73

---

(1) Derived from item 16 of Table 6.

(2) Drainage density is equal to stream mile divided by drainage area in mi^2.

(3) This value (1/DD) is equal to the reciprocal of the drainage density.

Source: Betz Environmental Engineers, Inc.

(C) Sediment Delivery Ratio of Hydrologic Groupings: The sediment delivery ratio of each hydrologic grouping of each subarea are determined using the criteria presented in Figure 17. Since the measured drainage densities of the subareas are grouped towards the flat ends of each soil type curve, the process was simplified and a single drainage density (the mean value) was employed for all of the study area. The resultant sediment delivery ratios for hydrologic groups in the Wissahickon are:

Group A - 0.2
Group B - 0.35
Group C - 0.52
Group D or U - 0.75

(D) Determination of Weighted Average Sediment Delivery Ratio: The weighted average of the sediment delivery ratio is calculated as follows:

$$SD_{LU} = (\%_A \times SD_A) + (\%_B \times SD_B) + (\%_C \times SD_C) + (\%_{D \text{ or } U} \times SD_{D \text{ or } U})$$

where:

SD_{LU} = Sediment delivery ratio of land use within subarea

$\%_A$ = Percent of land use within subarea in hydrologic group A

SD_A = Loading factor for group A soils.

The final weighted average sediment delivery ratios employed are presented in Table 17. Appendix H presents a sample calculation of sediment delivery ratios. The sediment delivery ratios are relatively high in that there are few Group A hydrologic soils in the study area, and there is a significant amount of impervious cover (type U hydrologic group). The Group A soils have the lowest sediment delivery ratio and the Group U have the highest sediment delivery.

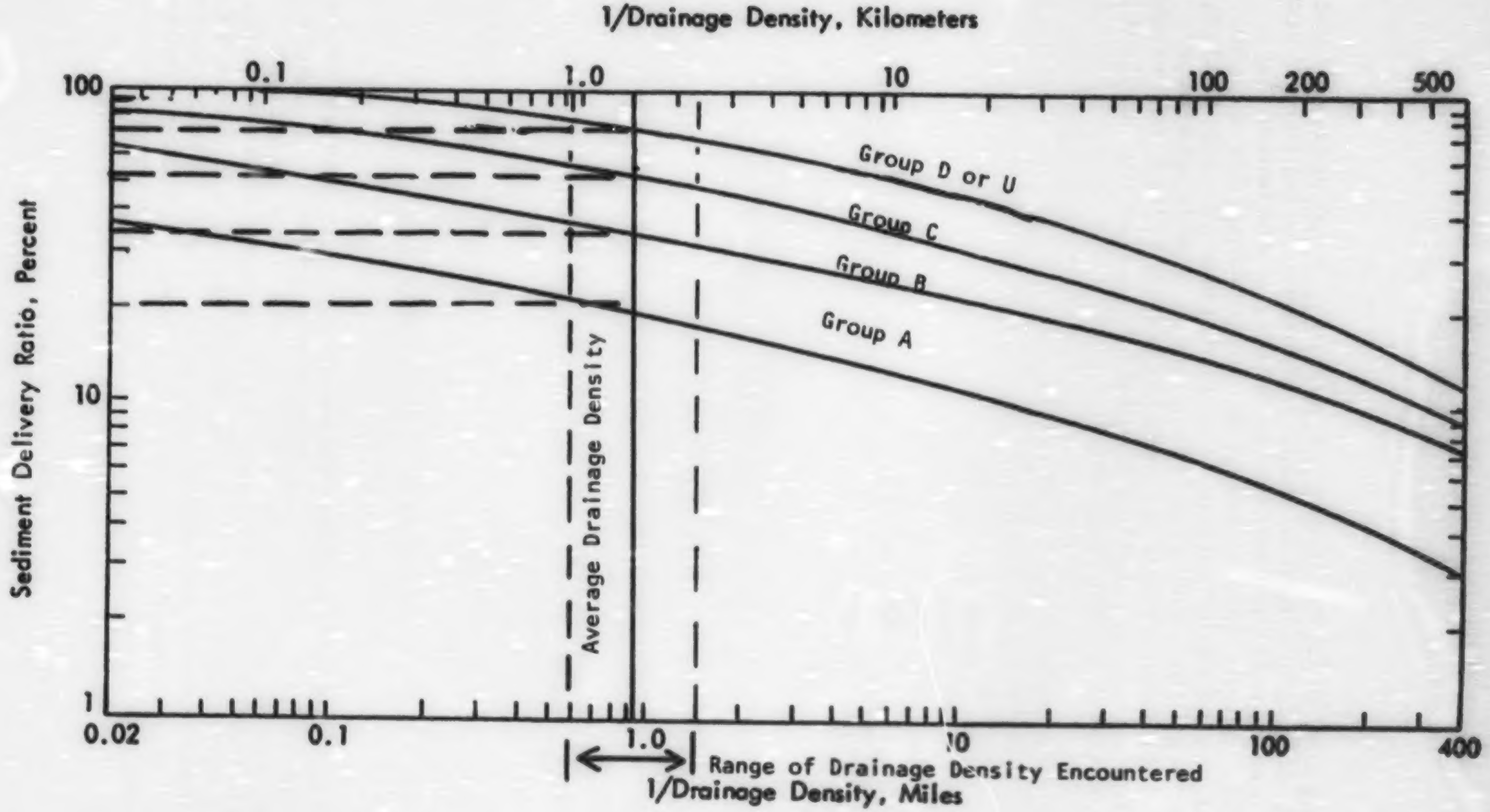


FIGURE 17

CRITERIA FOR DETERMINATION OF SEDIMENT DELIVERY RATIO

Source: Midwest Research Institute Criteria
Adopted to Hydrologic Groupings

TABLE 17

SEDIMENT DELIVERY RATIOS - WISSAHICKON WATERSHED(1)

Subarea	Sediment Delivery Ratio (SD)					
	Urban	Suburban Commercial	Residential	Cropland	Undeveloped	New Development
M-1	.68	.71	.37	--(2)	.58	.64
M-2	.62	.64	.42	.47	.42	.56
M-3	.70	.52	.59	.50	.55	.60
M-4	.59	.61	.50	.53	.50	.57
M-5	.64	.59	.68	.50	.59	.64
N1	.75	.72	.44	.35	.31	.64
O1	.75	.75	.70	--(2)	.27	.73

---

(1) Derived from items 9, 10, 16 and 17 of Table 6 and criteria presented in Figures 16 and 17

(2) Land use not present in subarea

Source: Betz Environmental Engineers, Inc.

4. Natural Controls Factor (P)

Natural controls consist of buffer strips adjacent to streams, and wetlands and marshes surrounding streams. In the Wissahickon Watershed there are no wetlands or marshes along the streams; however, there is significant buffering along the stream channels, especially in the Philadelphia area where the stream threads through the wooded areas of Fairmount Park. Unfortunately, these natural controls are bypassed to a large degree by storm drainage systems from urbanized areas which transport the nonpoint runoff pollutants directly to the stream. The effect of bypassing of buffer strips was included in the determination of the P factor. The P factor was determined as follows.

(A) The degree of buffering in each subarea was categorized and assigned load reduction rates as follows:

Wide Buffer - 0.5 load reduction
Medium Buffer - 0.25 load reduction
Narrow or No Buffer - 0.1 load reduction

Using the criteria from above a buffer factor (KA) was determined for each subarea.

(B) The bypass factor based on field observations and storm drainage maps was estimated in three classes for each land use in each subarea:

High Degree of Bypass - 0.9 bypassed or 0.1 unbypassed

Medium Bypass - 0.5 bypassed or 0.5 unbypassed

Low Bypass - 0.1 bypassed or 0.9 unbypassed

The factor (KB) was set equal to the unbypassed load.

(C) The P factor for each land use in each subarea was determined as follows:

$$P_{LU} = (1 - KA*KB)$$

where:

P_{LU} = P factor for land use within subarea

KA = Load reduction that would result if runoff were directed over the buffer strip

KB = Unbypassed fraction of runoff that is directed over the buffer strip.

The resultant P factors for each subarea/land use are presented in Table 18. A sample calculation of the P factor is presented in Appendix H.

5. Ratio of Other Pollutants to Sediment (KN)

If possible, the KN ratios should be based on measured runoff loads from typical land uses within the study area. There were no such measurements made in the Wissahickon Watershed; therefore, the KN ratios are based on measurements made in watersheds similar to the Wissahickon. The Occoquan/Four Mile Creek Study conducted by the Northern Virginia Planning Commission measured runoff loads from several sites during three storms. The mean value of pollutant loads from these storms are summarized in Table 19.

Based on the criteria presented in Table 19, the KN ratios for land uses in the Wissahickon Watershed were developed; they are presented in Table 20. Also shown for reference are the raw sediment loads (K) in lbs/acres/yr and the resultant equivalent raw pollutant load of each land use in lbs/acre/yr.

6. In-stream Consumption/Decay of Pollutants (K3)

The in-stream consumption and decay of pollutants varies with the pollutant and stream characteristics. For example, organic matter (measured as BOD loading) is a non-conservative material which decays with time and stream mile. Phosphorus and nitrogen are other non-conservative substances. Available phosphorus and nitrogen are readily consumed by algae. Effluents from domestic sewage treatment

TABLE 18

NATURAL CONTROL FACTORS (P) FOR WISSAHICKON WATERSHED(1)

Subarea	Natural Controls (P)					
	Urban	Suburban Commercial	Pesidential	Cropland	Undeveloped	New Development
M-1	.96	.98	.92	.91	--(2)	.95
M-2	.96	.98	.92	.91	.90	.95
M-3	.88	.93	.76	.73	.70	.86
M-4	.88	.93	.76	.73	.70	.86
M-5	.96	.98	.92	.91	.90	.95
N1	.80	.88	.60	.55	.50	.76
O1	.60	.60	.60	.55	--(2)	[illegible]

---

(1) Derived from items 11 and 16 of Table 6 and from information gained in field surveys

(2) None of this land use category found in these subareas

Source: Betz Environmental Engineers, Inc.

TABLE 19

POLLUTANT LOAD FROM VARIOUS LAND USES

		Load lbs/acre/inch rainfall (1)				Equivalent KN Ratio (2)		
Item	Land Use	Suspended Solids	Biochemical Oxygen Demand	Total Phosphorus	Total Nitrogen	BOD	Total P	Total N
1.	Single Family	16.9	2.14	.098	.590	.1266	.006	.035
2.	Town House	37.8	5.57	.159	.724	.147	.004	.019
3.	High Density	10.2	1.96	.058	.414	.192	.005	.041
4.	Shopping Malls	58.4	3.96	.157	1.41	.068	.003	.024
5.	Urban and Suburban Commercial - Average of 1, 2 and 3		.136	.004	.028			

---

(1) Based on average values of three storms in Occoquan/Four Mile Creek.

(2) Based on ratio of pollutant load to that of sediment

Source: Betz Environmental Engineers, Inc.; based on data presented in Occuquan/Four Mile Creek Study, Northern Virginia Planning Commission Quarterly Report, October 1976.

TABLE 20

POLLUTANT LOADING ANALYSIS FOR WISSAHICKON WATERSHED

Land Use	Suspended Solids Load lbs/acre/yr	KN Ratio / Equivalent Raw Loading (lbs/acre/yr): Biochemical Oxygen Demand	Total Phosphorus	Nitrogen	Heavy Metals[4]
Urban[1]	6,000	.136 816	.004 24	.028 168	.0013 7.8
Suburban-Commercial[1]	4,000	.136 544	.004 16	.028 112	.0013 5.2
Suburban-Residential[1]	1,000	.127 127	.006 6	.035 35	.0004 0.4
Agriculture/Cropland[2]	4,000	.03 120	.0009 3.6	.037 148	.0001 0.4
Undeveloped[2]	500	.01 5	.0009 0.45	.001 0.5	.0001 .05
New Development[3]	30,000	.01 300	.0003 9	.0017 51	.0008 24

---

(1) Based on loads presented in Occoquan/Four Mile Study, October 1976

(2) Based on loads presented in Correll *et al*, 1975

(3) Based on loads presented in Occoquan/Four Mile Study, January 1977

(4) Heavy metals based on loads presented in Guy, 1975

Source: Betz Environmental Engineers, Inc.

plants are usually higher in available phosphorus and nitrogen while nonpoint sources typically have lower percentages of available nitrogen and phosphorus. However, the nutrients attached to or in the form of suspended solids can settle in the slower-moving portions of the streams and result in subsequent nutrient enrichment as the particles are dissolved.

Conservative substances such as heavy metals typically have low removal rates.

Based on the above rationale the removal rates of pollutants were estimated as fractional parts of those determined in the steady-state water quality model for the Wissahickon (Gabriel, 1972) and on available literature values for typical stream decay rates.

Table 21 presents the K3 rates employed in the calibration model (1968 conditions). These rates were applied uniformly through the receiving streams.

TABLE 21

STORM DECAY RATES OF POLLUTANTS (K3) - WISSAHICKON WATERSHED

Parameter	Decay Rate %/mile of stream
Sediment	0.0
BOD_5	0.0125
Nitrogen	0.003
Phosphorus	0.003
Heavy Metals	0.001

H. LAND MANAGEMENT CONTROLS

Land management controls include municipal regulatory controls, maintenance controls and physical controls. A table of physical practices for construction activities was presented in the methodology section (Table 2). These physical controls are applicable to most regions of the country. Municipal regulatory controls and maintenance controls are listed in Appendix f. The controls are applicable to other study areas. For the Wissahickon Watershed, the existence of these regulatory controls in municipal codes was fairly representative.

The effect of land management controls are manifested in the K2 rate, which represents the reduction of the sediment yield to the stream resulting from existing land management practices. The practices included each of the three types of controls noted above. The following equation represents the logic of the management practice reduction factor (K2):

$$K2 = 1 - (K_{NLD} + K_O + K_A)$$

where:

1 = No reduction of load due to management practices

K_{NLD} = Reduction factor for management practices applied to New Land Development

K_O = Reduction factor for general land maintenance practices, not including that applied to new land development

K_A = Reduction factor for management practices applied to agricultural (crop) production

The following pages describe the derivation of the K_{NLD}, K_O, and K_A reduction factors by subarea and land use category.

1. New Land Development Control Effectiveness (^{K}NLD)

A point system for relative effectiveness was devised for potential new land development controls and is summarized below:

Points	Effectiveness of Regulatory Control
3	Significant load reduction
2	Moderate load reduction
1	Minimal load reduction
0	Zero load reduction

Table 22 lists each municipality in the study area and the existence of new land development controls. Scores of relative effectiveness, as noted above, were assigned to each control (see pp. 132-135 for derivation of effectiveness scores). The final two columns show the total score for each municipality and an associated "highest sediment reduction capability." As the table indicates, the City of Philadelphia and the Townships of Springfield and Whitpain in Montgomery County were associated with a highest sediment reduction capability of 95% from new land development based on the potential of their controls.

The means of deriving "sediment reduction capability" involved the analysis of municipal regulatory controls in effect in the study area for new land development. This analysis focused on the types of physical controls required by the ordinances which would in effect reduce sediment movement from the construction site. With an understanding of which physical controls were required (many of which are the same as those listed on Table 2), the literature was reviewed to determine documented evidence of control effectiveness. Since the primary emphasis was on controls which maintain sediment on-site, the controls of interest were those which protect exposed ground, control runoff velocity, filter sediment from runoff and contain sediment.

The highest reduction capability of 95% was associated with a regulatory control score of 18 in three municipalities. A review of each control program indicated a well developed program to control sediment through what can be described as

TABLE 22

MUNICIPAL REGULATORY CONTROLS FOR NEW LAND DEVELOPMENT - WISSAHICKON WATERSHED

Regulatory Controls and Requirements	Municipalities in Watershed											
	Abington	Ambler	Lansdale	Lower Gwynedd	Montgomery	North Wales	Philadelphia	Spring-field	Upper Dublin	Upper Gwynedd	White-marsh	Whitpain
Zoning Ordinance												
General Zoning Ordinance Contents	1	1	1	1	1	1	1	1	1	1	1	1
Mixed or Average Density Provision	1	1	-	1	1	1	1	1	1	1	-	1
Flood Plain Designation	2	-	2	2	2	-	2	2	2	2	2	2
Agricultural District Designation	-	-	-	-	-	-	-	-	-	1	-	1
Subdivision Ordinance												
General Subdivision Ordinance	3	3	3	3	3	-	3	3	3	3	3	3
Surface Drainage Plan	-	-	-	-	-	-	1	-	-	-	-	1
Net Runoff Limitations	-	-	-	-	1	-	1	1	-	-	-	-
Structures for Runoff Reduction On-Site	-	-	-	-	-	-	1	1	-	-	-	-
Structures for Sedimentation and Erosion Control On-Site	-	-	-	-	1	-	1	1	1	-	1	1
Control Maintenance	1	-	-	-	-	-	-	1	-	-	-	-
Tree Preservation	-	-	-	-	-	-	1	-	-	-	-	-
Connection to Public Sewers	1	1	-	1	1	1	1	1	1	1	1	1
Flood Plain Protection Ordinance												
Runoff Control	-	-	-	-	-	-	-	-	-	-	-	1
Erosion Control	-	-	-	-	-	-	-	-	-	-	-	1
Streambank Alteration Control	-	-	-	-	-	-	-	-	-	-	-	1
Watercourse Alteration Control	-	-	-	-	-	-	-	1	-	-	-	1
Stream Setback Control	2	-	-	2	-	-	-	2	-	2	-	-
Steep Slope Protection Ordinance	-	-	-	-	-	-	2	-	-	-	-	-
Planned Residential Development or Cluster Development Ordinance	-	-	-	-	-	-	-	-	2	-	-	-
Pennsylvania Sedimentation and Erosion Control Regulations	3	3	3	3	3	3	3	3	3	3	3	3
Municipal Regulatory Control Score	14	9	9	13	13	6	18	18	14	14	11	18
Highest Sediment Reduction Capability (Percent)	74%	40%	40%	60%	60%	30%	95%	95%	74%	74%	50%	95%

Note: - indicates that the regulatory control does not exist in the municipality

Source: Betz Environmental Engineers, Inc.

a system's approach, whereby a number of physical controls are required as lines of defense. Each line of defense may meet a certain objective and in combination the controls reinforce one another. This systems approach to sediment control has been documented in two EPA publications:

> Comparative Costs of Erosion and Sediment Control, Construction Activities, Office of Water Programs Operations, (EPA Contract No. 68-01-0755), July 1973.
>
> Nonpoint Source Control Guidance, Construction Activities, Office of Water Planning and Standards, (Technical Guidance Memorandum: Tech-27), December 1976.

The original source of data on control effectiveness for these two documents were the following:

> Dow Chemical Corporation, An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization (C-1677), Final Report, February 15, 1971-February 14, 1972.
>
> County of Fairfax, Virginia, Erosion-Siltation Control Handbook, Chapter 13 and Appendix, August 1972.

Each of these documents outlines promising systems for sedimentation control employing various forms of physical controls. The control systems documented were similar to requirements of the regulatory controls of the three municipalities cited in this study area. The literature sources indicated control effectiveness between 90 and 99%.

Based on this documentation, the most promising regulatory controls in this study area were assigned "highest achievable sediment reduction capability" of 95%. This figure, in turn, was used as a benchmark against which the controls of other municipalities were measured. A linear scale was used whereby 18 points achieved 95%, 9 points achieved 48%, 6 points achieved 30% and so forth.

A number of qualifications have to be made regarding this approach and the use of documented data. The benchmark figure of 95% is probably high for this study area and most others. The primary reason for such skepticism is that its use for measuring "regulatory control" effectiveness does not account for the probability of implementation, which is a variable of municipal and developer responsibility. Nonetheless, as a measure of control "capability," it was determined that the absolute number was not as significant to the methodology as the relationship of control effectiveness between municipalities. In an effort to illustrate variability between municipalities, the benchmark of 95% was useful. As guidance for other study areas, documented data should be reinforced by study area-specific data on the effectiveness of controls. The development of site-specific-data was beyond the resources of this case study.

(A) Derivation of K_{NLD} by Subareas: Since the methodology is developed on a subarea rather than municipal basis, the load reduction factors for new land development by municipalities were converted to a subarea reduction factor (see Table 23). Basically, the subarea factor is derived by determining the percent composition of each subarea by municipality. For example, in M4, since Lower Gwynedd is 80% of the subarea land area, its reduction factor (.68) is multiplied by .8. Since North Wales is 20% of the subarea land area, its reduction factor (.30) is multiplied by .2. Thus, for subarea M4, the new land load reduction factor is calculated as follows:

Lower Gwynedd. . . . . . (.68) x (.8) = .544
North Wales. . . . . . . (.30) x (.2) = .060
Total Subarea. 600

2. Maintenance Control Effectiveness (K_O)

Table 4 in Section III illustrated the maintenance controls and point ranges associated with each control. In this case study, the sediment load reduction factor for maintenance control effectiveness in developed areas was not determined for each minor civil division. Instead, scores were determined for five land use categories, excluding new land development. Table 25 illustrates the finding of a higher incidence of such controls in urban areas and a lesser representation in each of the other land use categories. Refer to Table 4 in Section III for the point range of each type of control.

TABLE 23

CONVERSION OF MUNICIPAL REDUCTION FACTOR FOR NEW LAND DEVELOPMENT TO SUBAREA REDUCTION FACTOR

Subarea	Subarea Composition		New Land Development Reduction Factor
M-1	Abington	90%	.74
	Upper Dublin	10%	
M-2	Upper Dublin	100%	.74
M-3	Upper Dublin	50%	.78
	Whitpain	30%	
	Whitemarsh	20%	
M-4	Lower Gwynedd	80%	.60
	North Wales	20%	
M-5	Lansdale	50%	.59
	Montgomery	20%	
	Upper Gwynedd	30%	
N1	Whitemarsh	50%	.76
	Springfield	40%	
	Philadelphia	10%	
O1	Philadelphia	100%	.95

TABLE 24

EXISTENCE AND DEVELOPMENT OF MAINTENANCE CONTROL PROGRAMS

Control Program	Type of Control	U	SC	SR	A	F
A	General Land Use Policy	1	1	1	1	
B	Public Cleanliness	2	2	1		
C	Controls on State and Local Road Building	1	1	.5	.5	.5
D	Controls on Maintenance Construction	2	1	.5		

An assumption was made that control programs A and B would typically be applied to activities generating low levels of sediment and accounting for only 25% of the non-new construction sediment load. Programs C and D together were assumed to address major activities generating about 75% of this projected load. These activities would include road building and maintenance as well as structural renovations and alterations.

Table 25 illustrates the distribution of the points for the control programs A-B and C-D for each land use category. Table 26 converts these points into a percent sediment load reduction factor.

TABLE 25

MAINTENANCE CONTROL PROGRAM SCORES BY LAND USE CATEGORY

	Urban	Suburban Commercial	Suburban Residential	Agricultural/ Cropland	Forest
Programs A and B	3	2	2	1	0
Programs C and D	3	2	1	.5	.5

TABLE 26

LOAD REDUCTION DUE TO MAINTENANCE CONTROLS

	Urban	Suburban Commercial	Suburban Residential	Agricultural/ Cropland	Forest
Programs A and B	15%	10%	10%	5%	0%
Programs C and D	50%	33%	17%	8%	8%

Table 27 takes into account the percent sediment load reduction factor and the percent of total sediment generated by activities under that program. The addition of the products WX and YZ yields a single composite reduction factor for existing development.

TABLE 27

COMPOSITE MAINTENANCE CONTROL REDUCTION FACTOR
BY LAND USE CATEGORY

	Urban	Suburban Commercial	Suburban Residential	Agricultural/ Cropland	Forest
% Reduction A + B Programs: W	15	10	10	05	00
% of total sediment generated by activities under A + B: X	25	25	25	25	25
% Reduction C+D programs: Y	.50	.33	.17	.08	.08
% of total sediment generated by activities under C + D: Z	.75	.75	.75	.75	.75
Composite Reduction Factor (WX x YZ)	.41	.28	.15	.07	.06

3. Agricultural Control Effectiveness (K_{AG})

Farmers in the study area, in cooperation with the County Conservation District and the USDA Soil Conservation Service, were engaged in a relatively successful program of erosion and sedimentation control in 1968 (the calibration year). Consequently, a reduction factor of .60 was derived for all agricultural land in the study area. The .60 figure represents a land conservation program of 90% sediment reduction existing on 2 out of every 3 acres of agricultural land and 1 out of 3 acres not under any conservation program.

4. Land Management Control Effectiveness (K2)

Results of K_2 derivation for study area: Using the equation $K_2 = 1 - (K_{NLD} + K_O + K_A)$ and based on the preceding derivation of each variable, Table 28 was constructed to summarize K_2 values for each land use category in each subarea.

TABLE 28

EXISTING LAND MANAGEMENT CONTROL RATES (K2) -
WISSAHICKON WATERSHED

	K2 Rates: 1968 Conditions					
Subarea	U	SC	SR	F	A	NLD
M1	.59	.72	.85	.26	.94	.29
M2	.59	.72	.85	.26	.94	.26
M3	.59	.72	.85	.26	.94	.22
M4	.59	.72	.85	.26	.94	.39
M5	.59	.72	.85	.26	.94	.41
N1	.59	.72	.85	.26	.94	.24
O1	.59	.72	.85	.26	.94	.05

Legend:
U = Urban
SC = Suburban Commercial
SR = Suburban Residential
F = Forest
A = Agricultural/Cropland
NLD = New Land Development

Source: Betz Environmental Engineers, Inc.

I. MASS BALANCE ANALYSIS

Based on the loading factors, calibration data sets and verification data sets previously presented, a mass balance model was constructed. The mass balance model uses the factor involved in the universal soil loss equation as explained previously in Section III. The model was calibrated to the 1968 land use, rainfall and water quality conditions and was verified to the 1964 land use, rainfall and water quality conditions.

1. Calibration

Using the raw loading factors and the modifier previously described, a computer mass balance model was used to calculate sediment loads at the summation points. The resultant loads, calculated by applying the various factors to the land uses in each subarea, agreed to within 10% of the measured sediment load at summation point 1 (Ft. Washington Station). Minor adjustments were then made in loading factors to obtain exact agreement.

Next, the KN ratios were employed along with the 1968 sediment calibration computer run to obtain loads for other pollutants, i.e., BOD_5, nitrogen, phosphorus and heavy metals. The results of the calibration runs for sediment and other pollutants are presented in Table 29. The actual computer runs showing details of the total loads are contained in Appendix B and sample calculations are shown in Appendix H.

2. Verification

The land use acreage was adjusted to approximate the expected 1964 (verification year) land use. The 1968 rainfall factors based on flow and rainfall were incorporated and the computer model was run. The results of the verification runs are presented in Table 30. Printouts of the computer runs are presented in Appendix C.

TABLE 29

CALIBRATION LOADS SUMMARY - WISSAHICKON WATERSHED(1)

	Summation Point 1		Summation Point 2		Summation Point 3	
	Total Load (lbs x 10^6)	Average Load Rate (lbs/acre/yr)	Total Load (lbs x 10^6)	Average Load Rate (lbs/acre/yr)	Total Load (lbs x 10^6)	Average Load Rate (lbs/acre/yr)
Sediment	12.25	469	16.87	564	22.32	819
BOD	0.314	12.0	0.460	17.8	0.638	26.7
Phosphorus	.0434	1.7	.0644	2.6	.0907	3.9
Nitrogen	.0838	3.2	.1231	4.8	.1717	7.3
Heavy Metals	.0114	0.44	.0168	0.66	.02347	1.0

---

(1) Based on results of calibration computer runs (Appendix B)

Source: Betz Environmental Engineers, Inc.

TABLE 30

VERIFICATION RESULTS - WISSAHICKON WATERSHED(1)

Year	R Factor	Calculated Load (lbs x 10^6) Summation Point 1	Summation Point 2	Summation Point 3	Error(4) %
1968	1.0	12.25	16.87	22.32	---
1964	.836(2)	10.26	14.19	18.83	4.3
1964	.887(3)	10.89	15.06	19.98	10.7

---

(1) Based on results of verification computer runs (Appendix C) and rainfall data, item 5 of Table 6

(2) R-Factor based on ratio of Total Stream Flow of 1964 to Total Stream Flow 1968.

(3) R-Factor based on ratio of Total Rainfall 1964 to Total Rainfall 1968.

(4) % Error based on ratio of calculated load to measured load (9.84 x 10^6 at summation point 1)

Source: Betz Environmental Engineers, Inc.

The verification results agreed closely with the 1964 measured sediment load. There was a 10.7% error when using an R-factor based on ratios of total rainfall and a 4.3% error when using an R-factor based on ratios of total stream flow.

It is expected that the R-factor based on flow ratios provided better results because flow measurements for both 1968 and 1964 were made within the Wissahickon Watershed at the Ft. Washington station, whereas rainfall measurements were made in watersheds adjacent to the Wissahickon Watershed. Rainfall measurements for 1968 were collected at the North Philadelphia Airport (approximately 15 miles east of the center of the Wissahickon Watershed). Rainfall measurements for 1964 were collected at Phoenixville (approximately 12 miles west of the center of the Wissahickon Watershed). The NOAA precipitation records represented the best available rainfall measurements for the area.

J. WATER QUALITY IMPACT ANALYSIS

The effects of nonpoint source pollutants on aquatic biota were analyzed based on (1) available biological data (2) water quality data, and (3) results of the field surveys. The basic steps followed were:

- Obtain water quality data indicative of both low flow and high flow conditions.
- Determine parameters present in concentrations potentially harmful to biota during storm runoff (high flow periods).
- Analyze existing biological data to determine degraded areas that appear to be caused by nonpoint sources.
- Conduct field survey of areas identified in Step 3 and determine whether they are affected by nonpoint sources.

1. Chemical Water Quality Analysis

A comparison of available water quality data on the Wissahickon Creek for steady-state (low flow) and average (high flow) conditions (Table 31) provides an approximate indication of the impact of storms on water quality. The steady-state suspended solids concentrations are much lower than the average concentration. This pattern indicates that high sediment loads occur during high flow periods. The concentrations do not differ between stations, indicating that a relatively consistent amount of sediment enters along the course of the stream. Nutrient concentrations are lower or approximately the same at high flow as compared to low flow, indicating a dilution factor. Although absolute pollutant loadings in lbs/day may in fact be higher at high flow, the immediate impact of a substance on the biota is primarily a function of concentration. The BOD data follow no consistent flow pattern, but concentrations decrease downstream as a result of biological consumption.

This cursory examination of the Wissahickon Creek chemical data indicates the greatest nonpoint source biological effects are from sedimentation and scouring during storm periods, and possibly from a reduction in dissolved oxygen concentrations as a result of BOD inputs. In order to determine whether the nonpoint source pollution indicated by the previous data is in fact affecting the aquatic biota, it is necessary to compare the existing biological data collected at stations affected by point sources with data collected in areas not affected by point sources. Figure 18 illustrates the stations sampled in a previous survey and a summary of the general biological conditions at the time the data were collected. Figure 18, in conjunction with the point source locations shown in Figure 19, indicates those areas and conditions influenced by point source discharges.

These data indicate organic enrichment is present at Station 2, above any known point source discharges. From Stations 3-5 point source pollution is so severe it masks any effects nonpoint sources may have. Nonpoint source organic pollution undoubtedly exists in this area; however, the precise nonpoint source pollution effects will not be apparent until the point sources are eliminated or reduced.

The effects of nonpoint source pollution are also difficult to assess further downstream because of the upstream point source loads. There is some observed improvement in biological quality from Stations 6 to 8, in the absence of

TABLE 31

WATER QUALITY DATA SUMMARY

	Concentration mg/1					
	Summation Point 1		Summation Point 2		Summation Point 3	
Parameter	Steady State(1)	Average(2)	Steady State(2)	Average(3)	Steady State(1)	Average(3)
Sediment(4)	7.8	130	7.8	137	7.8	140
BOD		14.6	8.8	8.5	1.4	4.3
Phosphorus		1.50	1.29	1.2	1.0	.97
Nitrogen		7.9	7.1	5.13	4.45	3.0
NH_3 NO_3			2.5 4.6		.25 4.2	
Heavy Metals		0.3	.26	.27	0.7	.51

---

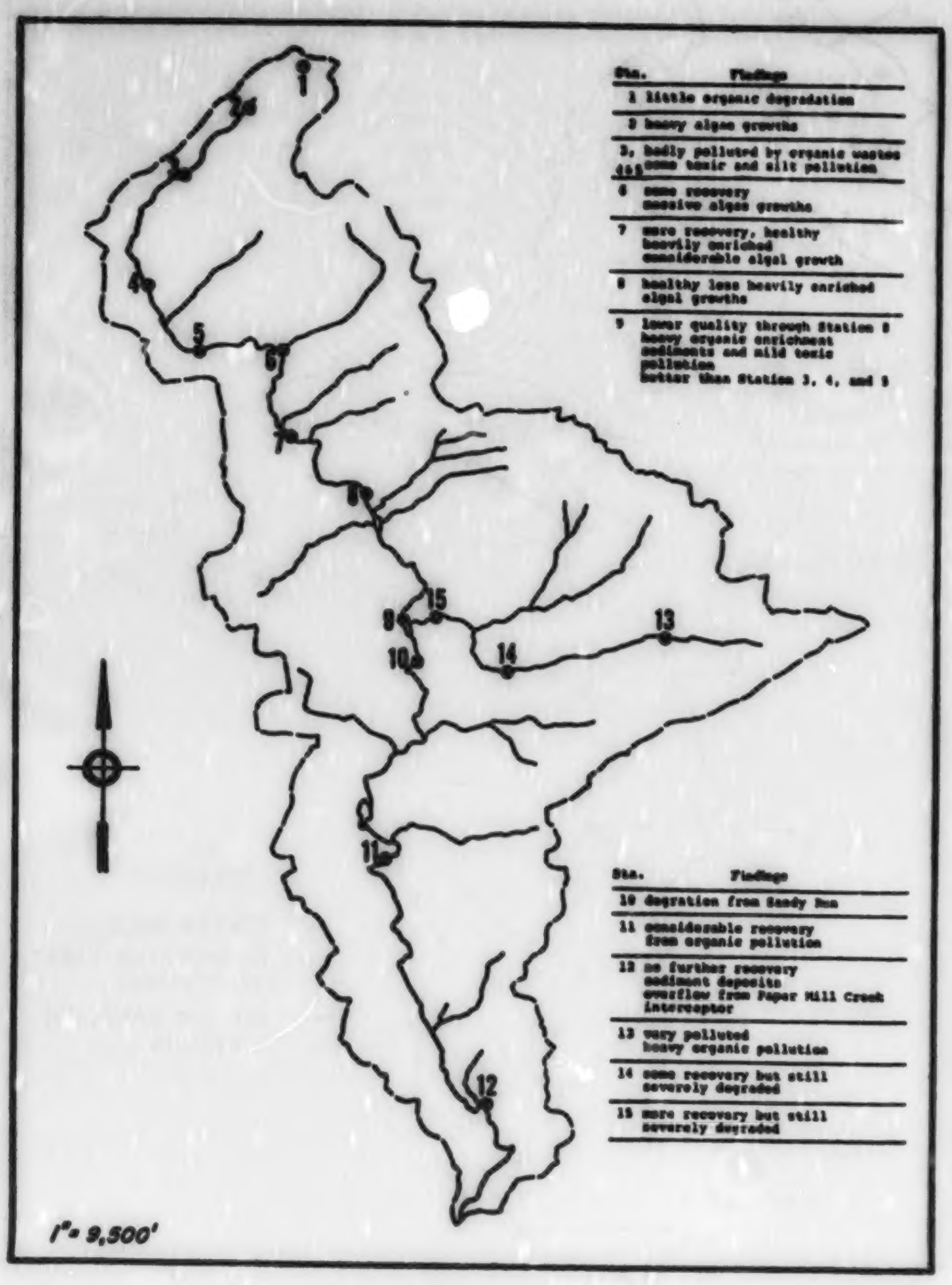
(1) Derived from data contained in items 1 and 2 of Table 6 and results of calibration computer runs in Appendix B

(2) Steady state low flow concentrations

(3) Average annual concentration based on flow

(4) Pattern indicates high concentration of sediment during storms

Source: Betz Environmental Engineers, Inc.



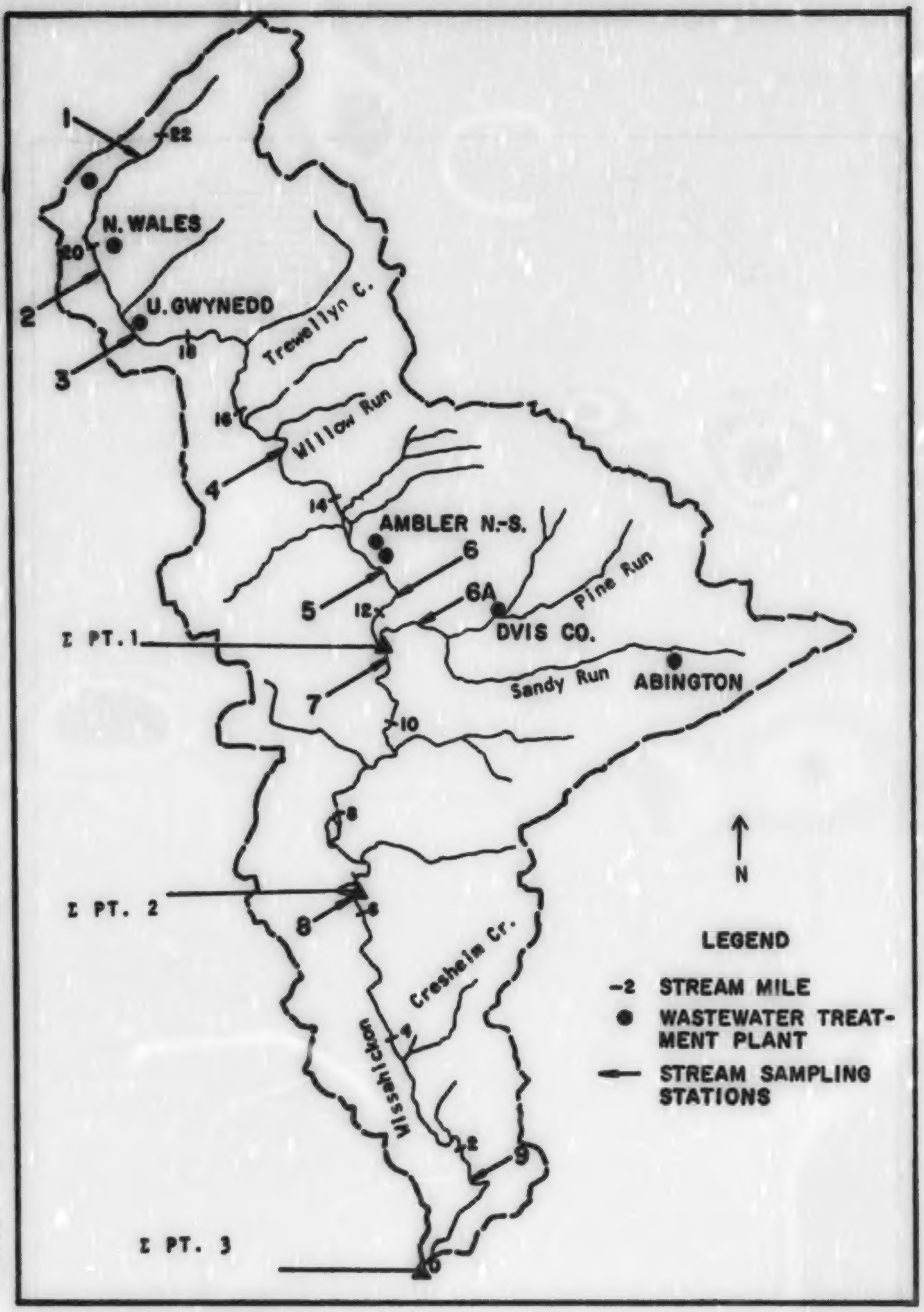
Sta.	Findings
1	little organic degradation
2	heavy algae growths
3, 4&5	badly polluted by organic wastes some toxic and silt pollution
6	some recovery massive algae growths
7	more recovery, healthy heavily enriched considerable algal growth
8	healthy less heavily enriched algal growths
9	lower quality through Station 8 heavy organic enrichment sediments and mild toxic pollution better than Station 3, 4, and 5

Sta.	Findings
10	degration from Sandy Run
11	considerable recovery from organic pollution
12	no further recovery sediment deposits overflow from Paper Mill Creek interceptor
13	very polluted heavy organic pollution
14	some recovery but still severely degraded
15	more recovery but still severely degraded

Source: Betz Environmental Engineers, Inc.

FIGURE 18

MAP OF BIOLOGICAL SAMPLING SITES
WISSAHICKON WATERSHED


1
22
N. WALES
20
2
U. GWYNEDD
3
18
Trewellyn C.
16
Willow Run
4
14
AMBLER N.-S.
6
5
12
6A
Pine Run
DVIS CO.
Σ PT. 1
7
Sandy Run
ABINGTON
10
8
N
Σ PT. 2
8
6
LEGEND
-2 STREAM MILE
● WASTEWATER TREATMENT PLANT
STREAM SAMPLING STATIONS
Cresheim Cr.
Wissahickon
4
2
9
Σ PT. 3
0

Source: Betz Environmental Engineers, Inc.

FIGURE 19

MAP OF POINT SOURCE DISCHARGERS, WISSAHICKON WATERSHED severe point source pollution. It is difficult to determine whether the extent of recovery is being affected by nonpoint source effects. Wissahickon Creek from Station 8 through 10, including the Sandy Run area, exhibits a pattern similar to that discussed above: severe biological degradation as a result of point source pollution, following by partial recovery.

It is not until Station 11 that point sources do not discharge into the stream. No noticeable improvement is observed between Stations 11 and 12, indicating nonpoint source pollution may be affecting the biological quality of the lower reaches of the stream.

Based on this assessment of the available data, it appears that significant parts of Wissahickon Creek are affected by nonpoint sediment loading. Portions of the stream are probably affected by nonpoint source oxygen demanding wastes and other pollutants but their effect is masked by the point source loads.

2. Biological Analysis

A cursory study of the watershed was performed to investigate the stream biota. Areas expected to be affected by nonpoint sources were emphasized. The results of the survey are presented below.

(A) The headwater area above known point discharges is biologically unproductive, but does not appear to be seriously affected by nonpoint source pollution. The main reason for this conclusion is the absence of siltation in the area. The probable reasons for the low productivity is the intermittent nature of the stream in the headwaters and possible scouring from a recent storm (this would be enhanced by nonpoint source runoff).

(B) Downstream, in the Ambler area, the stream does not appear to be seriously affected by nonpoint source pollution. Invertebrate organism diversity and algae growth did not appear to be reduced. Invertebrate organisms characteristic of good water quality conditions were present. The mainstream in this area does not appear to have a siltation problem, although it was apparent that heavy sediment loads are washed into the stream from feeder streams and stormwater runoffs. The sediment loads are apparently carried downstream by later storm events.

(C) The Sandy Run tributary upstream from the known sewage discharge appeared to be nutrient enriched. Algae growth appeared relatively heavy for the time of year and for following a recent heavy storm. The invertebrate community was greatly reduced and consisted of tolerant organisms. The source of the enrichment was not obvious and no sedimentation was apparent.

(D) The stream appeared heavily degraded downstream from the sewage treatment plant on Sandy Run. The absence of siltation indicated nonpoint source pollution was not a significant problem; however, there was evidence of high sediment loads being washed in from construction sites and storm drains. Like the Ambler area of the Wissahickon these sediment loads were washed downstream.

(E) At both the Bells Mills and Valley Green area below the confluence of Sandy Run with the Wissahickon Creek, water was a gray, murky color and biota were reduced and indicative of a degraded environment. In this reach, the stream consists of a series of riffles and pools. The pools collect large deposits of sediments which destroy the biological habitat. These sediment deposits are attributed to the upstream nonpoint source sediment loads in the Wissahickon Creek and Sandy Run.

(F) Further downstream below the confluence of Wissahickon and Cresheim Creeks and the dam, biological conditions appeared to be quite good. Both invertebrate and algal conditions were indicative of good water quality and no sedimentation was apparent. Above the dam, habitats were reduced and some sedimentation was apparent, indicating the dam was providing an area that collected sediment.

(G) Cresheim Creek, which drains an urban area, but has no point sources, was in fairly good biological condition. The invertebrate community was quite diverse, and there were no signs of storm scouring. There was a small amount of sediment present.

(H) At the mouth of the Wissahickon and approximately 1 mile upstream from the mouth, near a series of dams, there was heavy siltation and the biota were greatly reduced. Available habitats were heavily silted which was the probable reason for the absence of aquatic biota.

3. Summary of Analysis

In summary, the results of the water quality analysis indicate that:

(A) The temporary effects of nonpoint pollutant runoff do not have any noticeable effect on biological conditions. Stream concentrations of pollutants are not increased because nonpoint pollutant loads are accompanied by increased dilution flow.

(B) The Wissahickon Creek from the confluence of Sandy Run to approximately 1/2 mile above the mouth suffers from nonpoint source sediment loads. The habitat in pools and directly above impoundments are destroyed by settling of sediment loads. These loads result from upstream runoff from construction sites and storm drains.

(C) The biological condition at the mouth of the Wissahickon (last 1/2 mile of the stream) are completely destroyed by sediment loads. The slow stream velocities in this reach result in settling of large deposits of sediment.

(D) Even if point source pollutants were eliminated a significant portion of the Wissahickon Creek from the confluence of Sandy Run to the mouth will not recover biologically. Siltation in pools, areas above impoundments and the mouth region will continue since these problems result from nonpoint runoff loads.

(E) The total nutrient loads from nonpoint sources are large enough to significantly contribute to downstream eutrophication problems as indicated by the concentration of phosphorus and nitrogen resulting from runoff.

K. SENSITIVITY ANALYSIS

The sensitivity of land use, land management controls and loading factors were explored for all subareas. Table 32 presents a summary of the sensitivity analysis of the total study area. Results indicate that under existing conditions 50% or more of the loading is controlled by natural factors such as slopes, sediment delivery ratio and natural controls. The existing BMP controls provided approximately 50% reduction in pollutant loadings.

Subarea M3 was analyzed to determine the sensitivity of land uses to runoff loads. This subarea was selected because it represented an area in which significant development was taking place; thus it would reveal sensitivity to urbanizing factors. The results of this analysis are summarized in Table 33. Fifty percent of the urban land use sediment load is controlled by existing land management practices while only 26% of suburban commercial and 12% of suburban residential loads are controlled. Only 34% of construction loads resulting from new development are controlled. As such, the table indicates that the effectiveness of controls in subarea M3 is below the average of other subareas. This raised the question of how much improvement could be obtained in subarea M3 if the controls were upgraded. Consequently, the best controls in the study area were applied to the land uses in subarea M3 and the mass balance program was run. The results are summarized in Table 34. As can be seen, under existing land management practices 693 lbs/acre/year of sediment loading are controlled in the urban land loads. An additional 323 lbs/acre/year could be controlled by implementing best management practices in urban areas. New development land uses (areas under construction) showed the most promise for improvement. Under existing management practices, 968 lbs/acre/year are controlled, whereas using best management practices for new development (construction BMPs) would result in an additional 2,255 lbs/acre/year being controlled (reduced).

TABLE 32

SENSITIVITY ANALYSIS - TOTAL STUDY AREA, SEDIMENT %

Parameter	% of Impact on Runoff Load[1]		
	Subareas (M)	Subareas (N)	Subareas (O)
Slope Length (LS)	11	15	17
Sediment Delivery Ratio (SD)	32	25	17
Natural Controls (P)	6	16	28
Best Management Practices (K2)	51	44	38
Total	100	100	100

---

(1) Describes the relative impact of given parameters on load reduction within the listed subarea

Source: Betz Environmental Engineers, Inc.

TABLE 33

SENSITIVITY ANALYSIS - SEDIMENT - SUBAREA M3

	% of Impact on Runoff Load[1]					
Parameter	Urban	Suburban Commercial	Suburban Residential	Forest	Agriculture/ Cropland	New Development
Slope Length (LS)	9	7	18	18	8	14
Sediment Delivery (SD)	31	62	48	51	46	42
Natural Controls (P)	10	5	22	27	17	10
Best Management Practices (K2)	50	26	12	4	29	34
Total	100	100	100	100	100	100

---

(1) Describes the relative impact of given parameters on load reduction within the listed land use.

Source: Betz Environmental Engineers, Inc.

In terms of impact to total load from the subarea, BMP controls applied to construction would reduce the load from 2.447 million lbs to 2.093 million lbs/year. This represents a 15% load reduction for controls applied to only 2% of the land use within subarea M3. This indicates that cost-effectiveness results could be obtained by implementing construction controls. The analysis previously presented for construction controls in subarea M3 illustrate the use of sensitivity analysis in developing criteria for formulation control plans. Similar analysis could and should be applied to other controls and other subareas.

L. CONTROL PLAN DEVELOPMENT

The next step in the methodology is to evaluate nonpoint source controls. As noted previously, nonpoint source controls should be selected and the resulting pollutant

TABLE 34

SENSITIVITY, LAND USE CONTROLS, SEDIMENT - SUBAREA M3

Parameter	Description	Load Reduction							
		Urban		Suburban Commercial		Suburban Residential		New Development	
		Load Rate lbs/acre/yr	Load Change lbs/yrx10^6	Load Rate lbs/acre/yr	Load Change lbs/yrx10^6	Load Rate lbs/acre/yr	Load Change lbs/acrex10^6	Load Rate lbs/acre/yr	Load Change lbs/yrx10^6
K2(1)	Existing load changes as a function of Best Management Practices	693	0.842	243	0.0475	35	0.053	968	0.152
K2(2)	Additional load reduction possible under practical limits of Best Management Controls for urbanized and new construction	323	0.39	169	0.033	85	0.129	2,255	0.354

---

(1) Provides load reduction resulting from existing management practices

(2) Provides additional load reductions possible under conditions of implementation of best management practices in all of subarea M3. Best management practices correspond to those described for Springfield Township presented in paragraph L, Control Plan Development

Source: Betz Environmental Engineers, Inc.

reductions obtained. Nonpoint source and point source controls should be run through the water quality analysis in a reiterative process until the required pollutant levels are obtained, or until the best controls have been applied and additional improvements in water quality are not practical or obtainable. This reiterative process was not performed in this case study because it was beyond the scope of the study. The first step in this reiterative process, selecting and evaluating the most cost-effective nonpoint source controls, is presented in the following sections.

The water quality impact analysis indicated that sediment and nutrients (nitrogen and phosphorus) are the principal water quality pollutants associated with nonpoint sources. Therefore, the control plan must address these problem areas. The results of the sensitivity analysis were helpful in exploring and determining alternative control plans to accomplish this.

In the development of a control plan for the Wissahickon Watershed, the choice of types of controls for varying settings had to be understood. Urban, suburban commercial and suburban residential land use categories were subject only to "maintenance controls." These controls are exercised at developed sites undergoing renovation or alteration. They include labor and machine-intensive work in conjuction with on-site application of physical facilities or structures. The control plans for each of these three land uses were assumed to improve sediment reduction from 1968 to 1985 and from 1985 to 2000. (Consequently, the K2 rates associated with each connotes this change.) The 1985 control plans were assumed to include improved controls on state and local road building and repair as well as municipal regulatory controls on maintenance construction. By the year 2000, improvements in public cleanliness technologies (i.e., street cleaning, sewer flushing) employed as controls would be of sufficient worth to achieve the .40, .50 and .50 K2 rates for urban, suburban, commercial and suburban residential land uses, respectively.

Forest and undeveloped land were subject to no controls except for maintenance control programs for state and local road building. Agricultural lands were subject primarily to sedimentation and erosion control practices. These lands also were affected by maintenance control on state and local road building. The control plans for undeveloped and agricultural lands were assumed to be constant for the years

1968, 1985 and 2000. Consequently, the K_2 rates associated with each remained constant as well.

For new land development, the K_2 rates were derived from documented data on land development controls of each municipality (see Table 22). This was then converted to a subarea rate (see Table 23). In all instances, except for subarea O, the K_2 rate (identical in this case to K_{NLD}) was postulated to improve for the years 1985 and 2000. At the year 2000, all controls on new land development were assumed equal at a K_2 rate of .05. The types of controls necessary to achieve this K_2 level are exemplified in section L.1. This section notes that the highest rating of 95% reduction (equivalent to a K_2 of .05) was achieved in Springfield Township. The controls in place in Springfield are listed in that section. A comparable combination of controls are postulated to be present throughout the study area by the year 2000.

In Table 35, the existing and projected K_2 rates are presented for each land use category. The 1968 rates are based on existing control potential, subject to certain judgmental considerations relative to implementation probability. The years 1985 and 2000 K_2 rates were arbitrarily selected as performance goals for those time periods. As discussed in Section III, there are innumerable combinations of new land development controls, maintenance controls, and agricultural management controls which, in relation to one another, could achieve these desired levels of in-stream sediment and other pollutant yields. The physical controls listed in Table 2 can likewise be combined in innumerable ways to achieve a desired response.

1. Year 1968 Control: New Land Development

The most basic municipal regulatory controls (for new land development) instituted in this study area in 1968 included flood plain designation and management provisions, general subdivision ordinances, and sedimentation and erosion control regulations. In the Commonwealth of Pennsylvania, the regulations on sedimentation and erosion control are mandated and administered directly by the state through a permit system and through County Conservation Districts on a plan development basis. All municipalities are subject to this control.

TABLE 35

K2 RATES

Land Use	1968	1985	(1) 2000
Urban	.59	.50	.40
Suburban Commercial	.72	.63	.50
Suburban Residential	.85	.68	.50
Undeveloped	.94	.94	.94
Agriculture/Crops	.26	.26	.26
New Development M1	.29	.17	.05
New Development M2	.26	.16	.05
New Development M3	.22	.14	.05
New Development M4	.39	.22	.05
New Development M5	.41	.23	.05
New Development N	.24	.15	.05
New Development O	.05	.05	.05

Source: Betz Environmental Engineers, Inc.

(1) These reductions indicate no change in either undeveloped or AG/Crops, K2 rates, however, different strategy and actual water quality needs may necessitate or be more cost-effective than this control mixture.

With a few exceptions, each of the other two regulatory controls existed in each municipality. Consequently, a basic level of total load reduction, associated with having these controls, was assumed. This basic level was a 40% reduction factor for the flood plain, general subdivision, and sedimentation and erosion control regulations. Only North Wales, which did not have a subdivision ordinance, scored below this level. The 40% factor took into account the assumption that implementation of these basic controls was highly probable. While each of these controls actually differ (with the exception of sedimentation and erosion control) in terms of procedures by municipality, they were reasonably similar so as not to differentiate at that level of detail.

Higher reduction factors were achievable if other ordinances and ordinance components were in place in these municipalities which would have beneficial water quality impacts. Examples of these components in zoning ordinances included mixed or average density provisions, steep slope designation or agricultural district designation. In subdivision ordinances, these provisions included surface drainage plans, net runoff limits, structural requirements on-site and maintenance requirements. Finally, the use of other ordinances were accounted for, including steep slope ordinances and PRD or cluster ordinances. The highest rating of 95% reduction, in Springfield Township, for example, included, beyond the basics:

Mixed or average density zoning provision

Flood plain designation zoning provision

Net runoff limit subdivision provision

Required structures for runoff reduction on-site

Required structures for sedimentation and erosion control on-site

Required maintenance

Required connection to public services

Watercourse alteration criteria - flood plain provision

Stream setback requirement - flood plain provision

2. Year 1968 Control: Existing Development

For existing development, emphasis was on the use of maintenance controls for state and local road building and maintenance construction. The use of such controls in this study area was prevalent in the urban areas where renovation, alteration and overall improvements were most prominent. In some of the developed suburbs, where sediment generation was not relatively great, the existence of such controls was minimal, particularly for agriculture and undeveloped land uses.

3. Projected Controls - 1985 and 2000: New Land Development

As stated in Section III, two approaches for projecting future levels of control are to either delineate the use of specific physical controls in a municipal ordinance or to set performance standards on the ordinance which leave the perogative for control choice to the developer. In this case study, the performance standard approach was selected.

Since some municipalities in the study area had shown evidence of significant sediment reduction based on existing controls, it was assumed that all municipalities could achieve the K2 level of .05 by the year 2000, with an interim goal set for the year 1985. The technology for achieving these goals in this study area were believed to be available or potentially implementable. In the section on loading factor sensitivity it was made apparent that the land management controls to be placed on new land development by the year 2000 would result in the most significant instream sediment load reduction of all land use areas. Consequently the most cost-effective concern for control development, from the point of view of sediment reduction, would be controls placed on new land development. Once again, the level of regulatory control development cited for Springfield Township is indicative of the control package necessary to achieve performance standards as postulated here.

4. Projected Controls - 1985 and 2000: Existing Development

Unlike new land development controls, the information and technology for addressing pollutant generation from existing development is not as far advanced, although both forms require similar physical controls. The problem in this case study was one of assessing the pollutant generation problems, addressing the problem, and implementing the control program. The pollutant generation problem of existing development was associated most prominently with urban areas. The raw sediment production rates used for urban areas (6000 lbs/acre/year) is evidence of that assessment.

In this area of maintenance controls, the need for performance standards was determined to be the most practical approach, given the preliminary characteristics of the technology and problem assessment. At the same time, the performance goals for the years 1985 and 2000 were reasonably set at K2 rates of .50 for suburban areas and .40 for urban areas. It is assumed that these goals are achievable by instituting selected public cleanliness programs (i.e., street sweeping and litter collection) in conjunction with stricter controls on road building and street maintenance. The technology to reach these goals is currently available. When more advanced technology becomes available and the problems are better understood, the performance standards can be raised.

There is one additional qualification to be made regarding year 2000 K2 rates for existing land uses. Many of the controls on new land development have a carry-over effect as new construction sites become existing development sites over time. Some physical controls, such as detention basins, ditches and swales, and grade stabilization structures as examples, are maintained as controls beyond the construction phase. Moreover, the effect of implementing physical controls during construction may have a lasting effect on sediment generation from these developments over time which currently has not been well documented. Taking this into consideration, the K2 rates of .40, .50, .50 for urban, suburban commercial, and suburban residential, respectively, (see Table 35) could be increased, assuming the carryover effect of construction controls in conjunction with maintenance controls.

5. Impact on Stream Loading

The improvement in performance standards for the land management controls in conjunction with changing land use patterns between 1968 and 2000 resulted in a significant water quality response. Table 36 illustrates the stream loading at three points representing the summation of loads from the subarea. Subarea M includes the subareas M1-M5.

TABLE 36

STREAM LOAD BY SUBAREA
(lbs/acre/yr)

Subarea	1968	1985	2000	% Change 1968-2000
M	469	376	304	35.2
N	564	477	387	31.3
O	819	705	571	30.3

In order to focus on the water quality response associated with a single subarea, sediment loads (lbs/acre/yr) for each land use category in Subarea M3 are presented in Table 37 as an example. As indicated, the greatest decrease in sediment load was associated with new land development where the K2 rate changed from .22 in 1968 to .05 in 2000.

TABLE 37

SEDIMENT LOAD - SUBAREA M3
(lbs/acre/year)

	1968	1985	2000	% Change 1968-2000
Urban	1003	850	680	32.2
Suburban Comm.	627	548	435	30.6
Suburban Res.	206	165	121	41.2
Undeveloped	101	101	101	0.0
Agriculture/Crops	182	182	182	0.0
New Development	1771	1127	402	77.3

No change in sediment load (lb/acre/year) was achieved for undeveloped and agricultural lands where the K2 rates remained constant during this time period. For urban, suburban commercial and suburban residential land use categories, the percent change in sediment load between 1968 and 2000 varied from 32.2% to 41.2%. This change is based on achieving performance standards for maintenance controls on existing development.

Complete print-outs of the 1985 and year 2000 land use computer runs are contained in Appendix E.

V

EVALUATION OF METHODOLOGY

The methodology presented in this report provides a simplified approach to the analysis of land use/water quality relationships. The following sections present advantages and disadvantages of the methodology for this type of analysis and discusses problems encountered in the application of the methodology.

A. ADVANTAGES AND DISADVANTAGES OF METHODOLOGY

1. Data Requirements

An advantage of the methodology is that it uses data normally available from federal, state and local sources. These sources include, among others:

Data	Source
Precipitation	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
Soils Surveys	Soil Conservation Service, U.S. Department of Agriculture
Stream Flow	United States Geological Survey
Water Quality	U.S. Environmental Protection Agency - STORET
Land Use	County and Local Planning Agencies

The methodology also requires minimal collection and analysis of hydrologic and storm data, in contrast to dynamic storm modeling which requires more extensive data of this type. Overall, there are no significant disadvantages since most existing methodologies require similar or more data.

2. Ease of Implementation

The methodology uses a simplistic mass balance model based upon the universal soil loss equation. This equation has been found to have broad applicability and is suited to modification. The mass balance model can be calibrated and run without difficulty. Furthermore, parameter inputs to the mass balance model are easily derived from the data base. Although the model requires significant quantities of input data, it is much more manageable than that required for dynamic storm modeling.

3. Capability

The following are major capabilities of the methodology:

- Provides an assessment of the relative magnitude of nonpoint pollutant loads from varying land uses and subareas
- Permits the correlation and translation of visually observed problems (through field surveys) into quantitative assessments
- Provides an analysis of the sensitivity of varying land uses to in-stream loads to identify which land uses are major pollutant contributors
- The impacts of land uses and land management controls can be independently analyzed.
- Allows for exploration of alternative control programs for cost-effective analyses

The methodology cannot perform the following functions:

- It does not provide the detailed predictions of hydrological modifications produced by dynamic modeling.
- Water quality impact is not a direct output of the model; supplemental assessment using model output loads is required.

- The measurement of runoff pollutant loads is less accurate for soluble pollutants than for insoluble (sediment-borne) pollutants.
- Loads resulting from slow snow melt and long duration, low intensity rainfall are not adequately assessed.
- The universal soil loss equation is not well suited to measuring pollutant generation from impervious surfaces. A high sediment delivery ratio was assigned to impervious surfaces to approximate urban runoff conditions.

B. PROBLEMS IN APPLICATION OF METHODOLOGY

1. Rainfall Data

While the primary source for rainfall data was the National Oceanic and Atmospheric Administration, no such data were collected specifically for the Wissahickon Watershed. As a result, precipitation data for neighboring land areas were used. These data collection problems did not significantly alter results of the analysis since good correlation existed between rainfall data and stream flows.

2. Municipal and Hydrologic Coincidence

Resolution of differences between municipal and hydrologic boundaries was necessary in the selection of subareas. It was important to develop subareas based largely on hydrologic characteristics in order to permit the mass balance model to adequately reflect pollution conditions. However, once pollutant generation can be related to specific subareas, the step of designing land management controls is based largely on municipal programs and consequently varies by municipal boundary. In the process of moving from a subarea base to a municipal base, there is a problem of data translation. A method for addressing this problem is provided in the case study (see p. 133).

3. Man-Made Impacts on Natural Drainage

Where separate storm sewer systems exist in portions of a study area, much of the urban runoff is channeled through conveyance systems to outfalls and into streams. This changes what would otherwise be a nonpoint source generator into a point source generator. For this methodology, such man-made drainage systems are not adequately accounted for in the USCE-modified equation. In the case study of the Wissahickon Watershed, such systems were predominant in the City of Philadelphia. To account for this condition the P factor (buffer effect) and SD factor (sediment delivery) were evaluated to determine how closely actual conditions are being modeled.

4. Loading Rates

Resources did not permit field monitoring and sampling to determine study area-specific loading rates for urban mix, surburban commercial, suburban residential, agriculture, and undeveloped land. As a result, reliance was placed upon loading rates found in the available literature. While it was difficult to find complete documentation of loading rates for site description and storm conditions, the rates chosen were based on environmental conditions similar to that of the Wissahickon Watershed, such as:

- Intensity of land use
- Topographical features
- Climatic conditions
- Soil characteristics

5. Pollutant Ratios

In this methodology, pollutant loadings other than sediment are expressed as a ratio of the sediment load, since all are sediment-borne pollutants. Study area-specific data on pollutant ratios, however, were not available and were beyond the scope of this effort. Consequently, ratios were derived from areas in other studies exhibiting common land use and climatic characteristics. This is a problem which can be overcome by collecting data fitting local conditions through field monitoring, sampling and analysis.

6. Control Effectiveness

As in the case of loading rates, resources did not permit an examination of control effectiveness in the Wissahickon Watershed. Again, information from available literature was used. This information does not demonstrate much agreement in the effectiveness of physical controls, and less so for regulatory controls. Consequently, in this study, more emphasis was placed on the relative differences in control effectiveness, as opposed to absolute differences. BMP control effectiveness criteria are constantly being expanded and examined. Therefore, the state-of-the-art is increasing rapidly and this technology gap is being closed.

7. Implementation of Controls

In assessing the implementation of controls, this methodology focuses primarily on regulatory controls. Implementation affects both the municipality which enforces its land management regulations and the developers who must place controls on the land. In determining the probable effectiveness of land management controls for the model, the implementation factor must be accounted for in order to avoid projecting higher levels of effectiveness than can be realistically expected.

GLOSSARY

Abbreviation and Definitions of Key Variables

K factor:	raw loading rate (lbs/acre/yr)
KA factor:	fraction of load retarded due to buffer strip
KB factor:	fraction of load received by buffer strip
KAG factor:	reduction factor for management practices applied to agricultural (crop) reduction
KN ratio:	other (n) types of pollutant loadings, derived as a ratio of the sediment load
KO factor:	fraction of load reduced due to general land maintenance practices
K2 factor:	reduction of sediment load to stream from land management control practices
P factor:	reduction of sediment delivered to the stream as a function of natural controls such as buffer strips and marshlands
R factor:	(Rainfall factor) expresses the intensity and quantity of rainfall as a ratio of the rainfall conditions being considered to those encountered during the calibration conditions
LS factor:	(Slope Length) A dimensionless ratio expressing the effects of sloped terrain and its run length on the erosion and delivery of sediment to streams
SD Factor:	(Sediment Delivery Ratio) A dimensionless ratio expressing the function of sediment reaching streams. Factors consider proximity to receiving streams and soil runoff potential

Best Fit

The best agreement obtainable between model-generated nonpoint loads and measured stream loads for either calibration or verification conditions.

Calibration

The process of comparing and resolving differences between model-generated nonpoint pollution loads and measured stream loads. The model is simulating the same environmental and runoff conditions existing at the time of measured stream loads.

CFS - Day

The volume of water represented by a flow of 1 cubic foot per second for 24 hours (expresses total accumulated flow at a stream gauging station).

Curb-Mile

The distance of one mile of single curb length, or the length of one side of a street or other thoroughfare.

Drainage Density

The miles of drainage (streams, creeks and other tributaries) into which runoff flows, divided by the area of drainage.

Eutrophication

The aging process by which a lake or other water body evolves into a bog or marsh and eventually assumes a terrestrial state. Eutrophication may be accelerated by the impact of human activities.

Hydrograph

A graph of the quantity of water flow at a specific stream location as a function of time.

Land Management Controls

General term for category of controls on the use and treatment of land, including municipal regulatory controls, maintenance controls and physical controls.

Land Management Program

The combination of regulatory, maintenance and physical controls required by a municipality or other political jurisdiction for the management of land undergoing construction or alteration.

Loading Rate

The rate of discharge of a pollutant from its source to the stream.

Net Loading Rate

The rate of discharge of a pollutant to a stream which has been reduced by land management and natural controls.

Raw Loading Rate

The rate of discharge of a pollutant to a stream, excluding the effects of on-site land management and natural controls (expressed in this report as lbs/acre/year).

Maintenance Contruction

The renovation or alteration of a site or building to maintain or preserve its use. Buildings, bridges, roads and sidewalks are subject to maintenance construction.

Maintenance Controls

Controls required where sediment generation results from the renovation or alteration of existing developed sites, as well as from common daily accumulation of debris, litter and dirt.

Mass Balance

The measure and mathematical balance of accumulated pollutant loads washed off from land mass as compared to those loads measured at summation points. Considers the principle of conservation of mass.

Municipal Regulatory Control

Regulation, ordinance or local law covering land use and management requirements.

New Land Development

Land formerly in agricultural or undeveloped state undergoing construction for residential, commercial or industrial use.

Performance Standards

Specific, measurable levels of on-site control effectiveness, required as objectives of municipal regulatory controls. The *means* for achieving the required level of effectivness is not specified.

Physical Control

A structural or non-structural measure, which in its interface with the land, serves to alter or control natural processes such as erosion and sedimentation.

Pollutograph

A graph of accumulated pollutant load at a specific stream location as a function of time over the runoff period.

Sensitivity Analysis

A test of the significance of variables of the USLE - modified equation, in terms of effect on pollutant load.

Subarea

A part of a watershed, composed of a number of municipalities, used as a base-area for land use-water quality data collection and analysis.

Summation Point

A stream sampling station at a point on a major drainageway at which cumulative pollutant loadings and other factors are measured.

Verification

The process of comparing and resolving differences between model-generated nonpoint pollution loads and stream measured loads for storm and runoff conditions different than those expereienced for calibration conditions.

BIBLIOGRAPHY

1. American Public Works Association. "Nationwide Characterization, Impacts and Critical Evaluations of Stormwater Discharges, Nonsewered Urban Runoff and Combined Sewered Overflows," Monthly Progress Report to the U.S. EPA, August 1974.

2. Betz Environmental Engineers. "Wissahickon Watershed Wastewater Management Study," for Montgomery County, Pennsylvania, 1976.

3. Coughlin, R. E. and Hammer, T. R. "Environmental Study of the Wissahickon Watershed within the City of Philadelphia," Regional Science Research Institute, June 1973.

4. County of Fairfax, Virginia. "Erosion-Siltation Control Handbook," 1972.

5. Delaware Valley Regional Planning Commission. City of Philadelphia aerial photographs, 1975.

6. Delaware Valley Regional Planning Commission. "COWAMP/208 Storm Drainage Facilities Map," 1973.

7. Dow Chemical Corporation. "An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization," for U.S. Department of the Interior, 1972.

8. Engineering-Science Inc. "Comparative Costs of Erosion and Sediment Control, Construction Activities," for U.S. EPA (EPA 68-01-0755), 1973.

9. Gabriel, Claude. Wissahickon Water Quality Model (Unpublished report).

10. Grizzard, T. J. et al. "Assessing Runoff Pollution Loadings for 208 Planning Programs," A Study for the Northern Virginia Planning District Commission, 1977.

11. Hammer, Thomas R. "Planning Methodologies for Analysis of Land Use/Water Quality Relationships," A Study by Betz Environmental Engineers for the U.S. EPA (EPA 68-01-3551), 1976.

12. Harms, Leland L. *et al*. "Physical and Chemical Quality of Agricultural Land Runoff," *Journal of the Water Pollution Control Federation*, Vol. 46, No. 11, November, 1974.

13. Heaney, J. P. *et al*. "Stormwater Management Model, Level 1, Preliminary Screening Procedures," for the U.S. EPA, 1976.

14. Huber, Wayne C. *et al*. "Storm Water Management Model User's Manual - Version II," Prepared for U.S. EPA, 1975.

15. Hydroscience, Inc. "Simplified Mathematical Modeling of Water Quality," prepared for U.S. EPA, 1971.

16. Hydroscience, Inc. "Storm Water Management Model," (in progress).

17. Lager, J. A. and Smith, W. G. "Urban Stormwater Management Technology: An Assessment," Metcalf and Eddy, Inc. for U.S. EPA (EPA 670/2-74-040), Cincinnati, Ohio, 1974.

18. Loehr, Raymond C. "Characteristics and Comparative Magnitude of Non-Point Sources," *Journal of the Water Pollution Control Federation*, Vol. 46, No. 8, August 1974.

19. McElroy, A. D., Chui, S. Y., Nelogen, J. W., Aleti, A., and Bennett, F. W. "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," for U.S. EPA (EPA-600/2-76-151), Washington, D.C., 1976.

20. Montgomery County Planning Commission. "Montgomery County Land Use Map," 1972.

21. Philadelphia City Planning Commission. "Wissahickon Watershed Development Guide," 1976.

22. Real Estate Data, Inc. "Real Estate Atlas of Montgomery County, Pa.," 1976.

23. Roesner, L. A. *et al*. "A Model for Evaluating Runoff Quality in Metropolitan Master Planning," ASCE Urban Water Resources Technical Memorandum No. 23, 1974.

24. Sartor, James D. and Boyd, Gail B. "Water Pollution Aspects of Street Surface Contaminants," A study by the URS Research Company for the U.S. EPA (EPA-R2-72-081), 1972.

25. Soil Conservation Society of America. "Soil Erosion: Prediction and Control," 1977.

26. U.S. Army Corps of Engineers, Hydrologic Engineering Center. "Storage, Treatment, Overflow, Runoff Model (Storm Computer Program)," 1976.

27. U.S. Department of Agriculture, Soil Conservation Service. "Montgomery County Soil Survey," 1967.

28. U.S. Department of Agriculture, Soil Conservation Service. "National Engineering Handbook," 1964.

29. U.S. Department of Agriculture, Soil Conservation Service. "Philadelphia County Soil Survey," 1975.

30. U.S. Department of Commerce, National Oceanic and Atmospheric Administation. "Precipitation Records -Pennsylvania Annual Summary," 1963, 1964, 1967 and 1968.

31. U.S. Department of the Interior, Federal Water Quality Administration. "Storm Water Pollution from Urban Land Activity," Water Pollution Control Research Series, 11034 FKL, July 1970.

32. U.S. Department of the Interior, Geological survey. "Water Resources Data for Pennsylvania: Parts 1 and 2," 1964 and 1968.

33. U.S. Environmental Protection Agency, "Areawide Assessment Procedures Manual," Volume I (EPA 600/9-76-014), Cincinnati, Ohio, 1976.

34. U.S. Environmental Protection Agency. "Land Use Information for Water Quality Management Planning," Technical Guidance Memorandum No. 13, 1976.

35. U.S. Environmental Protection Agency. "Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Pollution," (EPA-430/9-73-007), 1973.

36. U.S. Environmental Protection Agency. "Nonpoint Source Control Guidance, Construction Activities," Technical Guidance Memorandum No. 27, 1976.

37. U.S. Environmental Protection Agency. "Storm Water Management Model: Level 1 - Comparative Evaluation of Storage, Treatment and Other Management Practices," (EPA-600/2-77-083), 1977.

38. Wanielista, Martin P. "Nonpoint Source Effects," State of Florida Department of Environmental Regulation, Technical Series, Vol. 2, No. 3, June 1976.

39. Weibel, S. R., Anderson, R. J., Woodward, R. L. "Urban Land Runoff as a Factor in Stream Pollution," Journal of the Water Pollution Control Federation, Vol. 36, No. 7, July 1964.